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1 **Sensitive Areas: Literature Review WATDOC References**

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7 **Athabasca Sand Dunes in Saskatchewan**

8 **Daily Hydrologic Model User Manual**

9 **Water Quality** (1983 publication date)

Cover Photo: Mackenzie River at Fort Simpson, Northwest Territories, looking downstream

Mackenzie River Basin Committee

Mackenzie River Basin Study Report

A report under the 1978-81 Federal-Provincial Study Agreement respecting the water and related resources of the Mackenzie River Basin.

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Letter of Transmittal

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August 1981

Gentlemen:

On April 1st, 1978, the Governments of Canada, Alberta, British Columbia, and Saskatchewan agreed to a study program designed to increase their understanding of the water and related resources of the Mackenzie River Basin, in order to facilitate future cooperation in planning and management for the best use of these resources. The Mackenzie River Basin Committee was directed to carry out appropriate studies and to report thereon.

On behalf of the Committee I am pleased to submit the comprehensive report entitled "Mackenzie River Basin Study Report." The Executive Summary presents the highlights of the report and its recommendations. In addition, there are nine supplemental volumes which contain substantially more detail on the resources of the basin. The report provides Canadians and others with a broader knowledge of this very large and complex northern drainage system.

Timely completion of the study, below budget, was made possible by excellent cooperation among government agencies, consultants, and other organizations that contributed to the work. This is the first such study for the basin as a whole and, indeed, for any of its subbasins. The results of the study indicate that water is the key resource in the basin and the principal interjurisdictional concern of the federal, provincial, and territorial governments.

The Committee wishes to express its appreciation for the continuing support it has received from the Ministers and their respective agencies.

Yours very truly,

Hans Foerstel

Hans Foerstel
Secretary
Mackenzie River Basin Committee

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Executive Summary

EXECUTIVE SUMMARY

This report describes a study of the water and related resources of the Mackenzie River Basin undertaken in 1978-81, the first to treat the basin as a whole. The study was designed to increase understanding of these important resources, their interdependencies, and the implications of water resource development in the basin. Recommendations arising from the study are addressed to the Governments of Canada, Alberta, British Columbia, Saskatchewan, Yukon Territory, and Northwest Territories, which participated in the project.

The resources of the Mackenzie Basin are of importance to all Canadians, and to the residents of the basin in particular. The conclusions and recommendations are based on an overview of the basin and the results of six main study components. The main issue identified is the need for future cooperation among the six governments in managing water, the one shared resource. How can the waters of this large basin be managed so that existing and potential uses will be handled equitably, and so that accepted environmental values in each jurisdiction will not be jeopardized?

The time to consider a transboundary water management agreement is now. Further developments could narrow the choices and raise the potential for conflict. Effective management can be best assured through a formal agreement among jurisdictions.

Four study components dealt with the basin as a whole and two with local areas. They are described below:

> A **network of measuring stations** is proposed which, if established, will provide the data for a coherent and comprehensive picture of the quantity and quality of water in the basin. If full advantage is taken of existing stations, the number of new stations will be kept to a minimum. The intent should be not only to fill serious data gaps in the basin, but also to ensure stability of the network, and consequently, reliability and usefulness of data. This is the first time that a basin-wide data network has been designed for the Mackenzie River Basin for water quantity, snow, meteorology, sediment, and water quality monitoring, or that an attempt has been made to integrate the individual networks into a comprehensive network.

A **computer model** was developed for the flows and levels of the major rivers in the Mackenzie River system. It can be used to simulate the downstream hydrologic effects of water resource projects and should be refined as more hydrometric information becomes available.

Although **spring ice breakup** has long been recognized as the most important annual hydrologic event in the Mackenzie River Basin, little work had been done on the Liard River system which normally triggers the breakup of the lower Mackenzie. This report documents the ice breakup, river temperatures, and sediment loads of the Liard River and its tributaries, and their influence on the Mackenzie River ice breakup below the Liard-Mackenzie confluence. An analysis of ice breakup mechanics and a description of the breakup sequence from south to north in the basin are included. Special attention was paid to ice jams, which cause particularly severe erosion and play a major role in flooding; aerial photography and infrared imagery were used extensively to study their location, extent, and timing. Because below-average flows occurred during the study period, knowledge about spring ice breakup will remain incomplete until similar events have been observed and recorded over a number of high-flow years.

The highly productive ecosystems in **alluvial areas**, where abundant and divergent vegetation provides food and shelter for a great variety of animal life, were the subject of one important study component. The productivity of alluvial areas depends on the annual spring ice breakup and later flooding. Alluvial areas, especially deltas, exert an influence far beyond their relative size; for example, the Peace-Athabasca, Slave, and Mackenzie Deltas are of international significance for migratory birds. The fact that this one river basin contains three significant deltas emphasizes the need to understand the alluvial processes. Accordingly, a comprehensive study of the Mackenzie Delta is recommended.

One of the study components provided the first systematic inventory of the resources and hydrology of the **Slave River Delta**, a biologic setting which offers diverse breeding, rearing, and feeding habitats that are not available in the surrounding boreal forest. The Slave River Delta is located on three migratory bird flyways of North America and therefore is important to continental waterfowl populations. Its fish and muskrats provide income for the residents of Fort Resolution. Like other alluvial areas, the delta depends on the annual spring ice breakup and flood for its productivity.

A sixth study component provided the first systematic inventory of the resources and hydrology of another area, the **Athabasca Sand Dunes** in Saskatchewan. The dunes, which are the largest area of open sands at such a northern latitude, are ecologically and aesthetically unique in the north. Delicately balanced between the forces of erosion and the enduring, self-renewing stability of a characteristic biological community, the sand dunes provide a diverse and captivating landscape contrasting markedly with the surrounding forests and muskeg. They are highly sensitive to disturbance, including changes in the hydrologic system. The greatest impact would result if the normal range of Lake Athabasca water levels or river flows through the sand dune area were changed.

Water is the essential natural resource of the Mackenzie River Basin. It provides habitat for fish and wildlife, and for the food chains which support them. Other resources, such as coal, gas, oil, tar sands, and minerals require large amounts of water for their development. Communities need water. Navigation and hydroelectric power production add to the growing competition for water. Development of any resource, be it in one jurisdiction or several, could affect the uses of water by altering flows, levels, or water quality downstream. Hence, the need for cooperative management represents the greatest and most urgent challenge for the future and heads the list of recommendations which follow.

1 **It is recommended that the jurisdictions at an early date conclude an agreement through which trans-boundary water management issues such as minimum flows, flow regulation, and water quality can be addressed at jurisdictional boundary crossing points in the Mackenzie River Basin, and which establishes a permanent board to implement the provisions of the agreement.**

2 **It is recommended that the proposed integrated long-term network of hydrometric, snow, meteorologic, sediment, and water quality stations outlined in this report be implemented.**

3 **It is recommended that precipitation, streamflow, and lake levels be evaluated for the entire basin to determine variability over time and space, and that the relationships among all parts of the water budget be analyzed and modelled.**

4 **It is recommended that the computer model of the river system developed in this study be continually refined and updated as additional hydrometric data are collected and as changes occur on the river system.**

5 It is recommended that the monitoring and analysis of the processes involved in spring breakup and sediment transport in selected streams in the Liard River Subbasin be continued until several high-flow years have been documented, and that the study area be extended to include the Mackenzie River from Fort Simpson to its mouth.

6 It is recommended that a comprehensive study of the Mackenzie Delta be undertaken to determine the relationships among the processes of delta change; and the vegetation, fish, and wildlife resources; and the hydrologic regime.

7 It is recommended that each jurisdiction in the Mackenzie River Basin, when considering a project proposal, follow an environmental assessment process that accommodates the interests in other jurisdictions in an equitable manner.

8 It is recommended that the program of abstracting documents regarding water and related resources in the Mackenzie River Basin for entry in the national water document data base (WATDOC) be continued.

9 It is recommended that the jurisdictions recognize the increasing level of interest in the resources of the Mackenzie River Basin and ensure that any new information on the resources and their development is made available to each other and to the public in a timely fashion.

RÉSUMÉ DE L'ÉTUDE

Le présent rapport, le premier à traiter du bassin fluvial du Mackenzie dans son ensemble, décrit une étude réalisée de 1978 à 1981 sur les ressources en eau et les ressources connexes du bassin. Les recommandations qui en découlent s'adressent à l'administration fédérale ainsi qu'à celles de l'Alberta, de la Colombie-Britannique, de la Saskatchewan, du Yukon et des Territoires du Nord-Ouest qu'ont pris part à la réalisation de l'étude. Cette dernière avait pour but de mieux faire comprendre la nature de ces importantes ressources, leurs interactions et les effets de la mise en valeur des ressources en eau dans le bassin.

Le bassin du Mackenzie est pourvu de ressources auxquelles tous les Canadiens, notamment les résidents du bassin, attachent de l'importance. Les conclusions et les recommendations de cette étude reposent sur une vue globale du bassin et sur le produit de six principaux volets. Le fond du débat réside dans la nécessité d'obtenir, pour l'avenir, une collaboration des six gouvernements pour la gestion des eaux, cette ressource partagée. Car, comment est-il possible d'assurer une gestion des eaux de ce vaste bassin, qui soit équitable tant pour les utilisations actuelles qu'éventuelles et qui ne vienne pas modifier les normes environnementales établies dans chacune des juridictions?

Il faut donc songer dès maintenant à négocier une entente concernant la gestion des eaux transfrontalières puisque l'aménagement d'autres installations pourrait limiter les possibilités et accroître l'éventualité de conflits. La conclusion d'une entente formelle entre les juridictions serait la solution pour en arriver à une gestion efficace des ressources.

Quatre des volets de la présente étude traitent du bassin dans son ensemble tandis que les deux autres portent sur deux régions précises. En voici un aperçu:

> Dans un premier temps, on propose d'établir un **réseau de stations de mesurage** qui, si elles sont aménagées, fourniront les données propres à procurer une vue cohérente et complète des aspects quantitatifs et qualitatifs des eaux du bassin. Une utilisation globale de toutes les possibilités qu'offrent les stations en place permettra de réduire au minimum le nombre de nouvelles stations à aménager. Il ne s'agirait donc pas de s'attacher simplement à combler les importantes lacunes qui existent au plan des données, mais aussi d'assurer la stabilité du réseau et, par le fait même, la fiabilité et l'utilité des données. Le réseau nouvellement conçu pour la collecte de données tant sur la quantité de l'eau, les neiges, les conditions météorologiques et les sédiments que sur la surveillance exercée pour assurer la qualité des eaux se veut une première ou encore une tentative d'intégrer en un seul réseau tous les différents réseaux.

Au cours de la présente étude, on a également pris soin d'élaborer un **modèle informatisé** pour les niveaux et les débits des principales rivières du réseau fluvial du Mackenzie. Ce modèle peut servir à simuler les effets hydrologiques en aval de projets associés aux ressources en eau et devrait être mis à jour à mesure que de nouvelles données hydrométriques sont accessibles.

Il est un fait que la **débâcle printanière** est depuis longtemps l'événement annuel à se produire sur le plan hydrologique, dans le bassin fluvial du Mackenzie. Peu a été accompli jusqu'ici sur le réseau de la rivière Liard, lequel est normalement à la source de la débâcle sur le cours inférieur du Mackenzie. Le présent rapport renferme des données sur la débâcle, les températures de l'eau et les charges en sédiments accumulées dans la rivière Liard et ses tributaires de même que sur l'effet qu'ont ces facteurs sur la débâcle du fleuve Mackenzie, en aval de son confluent avec la rivière. On y retrouve également une analyse du processus des débâcles et une description chronologique de la débâcle dans le bassin en allant du sud au nord. On s'est attardé tout particulièrement aux embâcles qui sont la cause d'érosions assez graves et jouent un rôle important dans les inondations. À l'aide de la photographie aérienne, et des images infrarouge dont on a fait grand usage, on a pu étudier l'emplacement des glaces et en déterminer l'étendue ainsi que le moment où elles se sont formées. Toutefois, en raison des crues au-dessous de la normale enregistrées durant la période à l'étude, l'information qu'on a pu en retirer reste incomplète et le demeurera jusqu'à ce qu'on ait eu la possibilité d'observer à nouveau des événements semblables et d'enregistrer des données pendant plusieurs années de hautes eaux.

Les écosystèmes très productifs intégrés dans des **zones alluviales**, où abonde une végétation diversifiée qui fournit nourriture et abri à une faune animale très variée, fait l'objet d'un volet majeur de l'étude. La productivité des zones alluviales est fonction de la débâcle printanière et des inondations qui s'ensuivent. L'influence de ces zones, notamment celle des deltas, est de plus bien supérieure à leur dimension réelle (p.e. les deltas des rivières de la Paix-Athabasca, des Esclaves et du fleuve Mackenzie sont reconnue internationalement comme étant une halte ou un gîte pour les oiseaux migrateurs. Étant donné que ce bassin fluvial compte trois importants deltas, on est davantage enclin à vouloir comprendre les processus alluviaux. Par conséquent, on recommande la réalisation d'une étude exhaustive sur le delta du Mackenzie.

Un autre des volets de cette étude renferme le premier inventaire systématique des ressources fauniques et hydrologiques du **delta de la rivière des Esclaves.** De composition biologique, ce delta offre des milieux divers pour la reproduction, l'élevage et l'alimentation qu'on ne retrouve pas dans la forêt boréale avoisinante. Il est situé sur trois voies migratoires de l'Amérique du Nord et de fait, représente beaucoup pour le gibier d'eau du territoire. Les résidents de Fort Resolution tirent leurs revenus de la pêche et de la trappe de rats musqués vivant dans le delta. Comme c'est le cas d'autres zones alluviales, la productivité du delta est le reflet de la débâcle printanière annuelle et des inondations.

Enfin, le sixième volet de l'étude présente le premier inventaire systématique des ressources fauniques et hydrologiques mais, d'une autre région cette fois, celle des **dunes du lac Athabasca** en Saskatchewan. Il s'agit de la plus vaste étendue de sable à une latitude nord. Les dunes sont d'une beauté et d'une écologie uniques dans le nord. En équilibre fragile entre les forces de l'érosion et de la stabilité durable et toujours renouvelée d'une communauté biologique qui les caractérise, les dunes dessinent un paysage à la fois différent et captivant de par le contraste marqué qu'il y a entre les forêts et le muskeg qui les entourent. Elles sont en outre très sensibles aux changements y compris à ceux d'ordre hydrologique. Si les niveaux d'eau du lac Athabasca et les crues sur la rivière devaient augmenter au-delà de la normale, il en résulterait le pire bouleversement que cette région n'ait jamais connu.

Dans le bassin fluvial du Mackenzie, l'eau constitue une ressource naturelle vitale. Elle procure l'habitat à la faune animale et halieuthique et aux chaînes alimentaires qui en assurent la survie. L'exploitation d'autres ressources telles que le charbon, le gaz, le pétrole, les sables bitumineux et les minéraux requiert beaucoup d'eau. Ses localités en ont aussi besoin. La navigation et la production d'hydro-électricité se joignent au rang des utilisations d'eau pour lesquelles la concurrence est de plus en plus vive. La mise en valeur d'une ressource quelconque, au sein d'une ou de plusieurs juridictions, pourrait avoir des répercussions sur les utilisations de l'eau soit en modifiant les débits, les niveaux ou la qualité en aval de l'installation, d'où la nécessité d'une gestion concertée. Voilà à quoi se résume le défi de taille qu'il faut relever au plus tôt. La liste des recommandations qui suivent servira à cette fin.

1 On recommande que les juridictions ratifient au plus tôt une entente qui rendrait possible la discussion sur des questions ayant trait à la gestion des eaux transfrontalières (débits minimaux, régularisation des débits et qualité des eaux aux frontières juridictionnelles dans le bassin du Mackenzie) et qui impliquerait la formation d'un comité permament chargé de voir à la réalisation des stipulations de l'entente.

2 On recommande que soit mis en œuvre à long terme la proposition d'un réseau intégré de stations hydrométriques, nivométriques, météorologiques, sédimentologiques et pour la surveillance de la qualité des eaux dont une description succinte est contenue dans le présent rapport.

3 On recommande qu'on évalue, pour l'ensemble du bassin, les niveaux de précipitation d'écoulement et les niveaux d'eau des lacs afin d'en déterminer la variabilité dans le temps et l'espace et qu'on fasse l'analyse et la modélisation des rapports liant tous les éléments du budget affecté aux ressources en eau.

4 On recommande que le modèle informatique du réseau fluvial élaboré dans le cadre de cette étude soit amélioré et mis à jour à mesure que des données hydrométriques supplémentaires seront recueillies et que des modifications au réseau seront réalisées.

5 On recommande que se poursuive la surveillance et l'analyse des processus engendrés par la débâcle printanière et le transport de sédiments dans des cours d'eau choisis situés à l'intérieur du sous-bassin de la rivière Liard jusqu'à ce qu'on ait pu établir un dossier après plusieurs années successives où l'on y aura enregistré des hautes eaux; que soit élargie la portée de la zone étudiée pour y inclure la section du fleuve Mackenzie de Fort Simpson à son embouchure.

6 On recommande qu'une étude exhaustive sur le delta du Mackenzie soit réalisée afin de déterminer les rapports reliant les processus de changement du delta ainsi que les ressources halieutiques, végétales et fauniques ainsi que le régime hydrologique.

7 On recommande que l'étude d'une proposition de projet présentée à une juridiction du bassin du Mackenzie soit réalisée selon un processus d'évaluation environnementale qui respecte de façon équitable les intérêts des autres juridictions.

8 On recommande que le centre WATDOC poursuive la rédaction de résumés pour les documents reliés à l'eau et aux ressources connexes du bassin et permettre ainsi leur inclusion à banque nationale de données sur l'eau (WATDOC).

9 On recommande que les juridictions reconnaissent la prise de conscience accrue en ce qui a trait aux ressources du bassin du Mackenzie et s'assurent que les nouvelles données, tant sur les ressources que sur leur mise en valeur, soient rendues accessibles, au moment opportun aux autres juridictions et au public en général.

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A. Study Background
B. Study Program
C. Study Report

Introduction

1

The Mackenzie River is at the heart of a huge river system, the largest and longest in Canada. Its basin encompasses portions of British Columbia, Alberta, Saskatchewan, the Yukon Territory, and the Northwest Territories.

Many large areas of the Mackenzie River Basin are virtually unchanged wilderness, with resource wealth that presents many opportunities for development. One prerequisite to socially desirable development is an understanding of the water and water- related resources of the basin. Through the Mackenzie River Basin Committee the federal, provincial, and territorial governments therefore conducted a program of studies on these resources from 1978 to 1981. This is the report of that Committee.

A. Study Background

The Mackenzie River Basin first received the attention of all basin governments in 1972 when 40 delegates met in Inuvik, N.W.T. to discuss concerns associated with future development possibilities in the basin. As a result of this meeting, the Mackenzie River Basin Intergovernmental Liaison Committee was formed to exchange information regarding studies, research, and intended developments. During 1972-77 the Liaison Committee examined and discussed ongoing planning and research activities, and identified certain interjurisdictional issues.

Study Agreement On May 31, 1977, federal and provincial Ministers signed a Memorandum of Understanding which re-established the Liaison Committee as the Mackenzie River Basin Committee, and formulated the idea of a three-year study program aimed at gaining a better understanding of the basin. The Committee then prepared the Mackenzie River Basin Study Agreement, which was signed by the Governments of Canada, British Columbia, Alberta, and Saskatchewan on April 1, 1978. The Agreement called for a report on the study to be submitted by the Committee to the Ministers by August 31, 1981, with costs not to exceed $1 600 000 (Appendix D).

The Mackenzie River Basin Committee consists of twelve members: four representing Canada, one each representing the Yukon and the Northwest Territories, and two representing each of British Columbia, Alberta, and Saskatchewan. Members who served on the original and the successor committee are listed in Appendix D, and those involved during the study program are listed on the back of the letter of transmittal.

Study Organization The Committee was responsible for directing the study and allocating funds provided under the Agreement. A Task Force, appointed by the committee, monitored study progress and prepared study programs, budgets, and work plans for the Committee. Advisory groups provided technical advice for the conduct of some study components.

Administrative support for the study was provided by Environment Canada. The study office was established in Regina under the direction of the Task Force chairman who was assisted by a study coordinator.

B. Study Program

The program comprised the following study components:

1. Pipeline Documents Review
2. Information Exchange
3. Hydrologic Systems
4. Potentially Sensitive Areas
   - A. Compilation of Existing Information
   - B. Slave River Delta
   - C. Athabasca Sand Dunes
   - D. Socio-Economics
   - E. Alluvial Ecosystems
5. Spring Flood
6. Public Information.

Two major changes were approved by the respective Ministers as part of the annual work program and budget. A study of the Slave River originally included in this program was deleted because the work is included in a major study of Slave River hydroelectric power potential being undertaken by Alberta. The results of that study will be made available to the Mackenzie River Basin Committee. The alluvial ecosystems study was added because an understanding of the interactions between rivers and alluvial areas was considered to be important for the Mackenzie River Basin.

The study program was completed about $250 000 below budget.

Work Assignments The work in the study program was undertaken through contractual arrangements with appropriate federal, provincial, and territorial agencies; private consultants; and university departments.

Public Information Since the study was essentially a scientific and data gathering exercise, and did not deal with actual projects or development plans, there was no overall need for public consultation. However, the public was kept informed by several means: a report on the proposed activities for each of the three study years, a slide-tape show and three information pamphlets, public meetings at Fort Simpson and Fort Resolution, and the hiring of a community liaison officer in Fort Resolution during the first year of the Slave River Delta field work. The annual reports of the Mackenzie River Basin Committee were also made available to the public.

C. Study Report

This is the main report for the study program and includes summaries of the study findings, conclusions, and recommendations. Considerable background information was included in Chapter 2 because so little information is available anywhere for the basin as a whole. The report is supplemented by nine separate technical reports which are listed on the inside front cover.

Some of the study components are discussed in this report under headings different from those listed in Section B above. Compilation of existing information and socio-economics are included in various sections of Chapter 2. The spring flood component was renamed spring breakup and is discussed in Chapter 4. The results of the hydrologic systems component are reported in Chapter 5 and Appendix C.

This report deals with extremely complex processes in nature, which take a long time to record and describe before they can be understood. The report therefore does not deal with specific projects, but with the establishment of a reliable water information base for the basin as a whole. This is a major challenge because such a base must serve many purposes well into the future, for an area no less than one fifth of Canada. This report is but a modest beginning in meeting that challenge.

The credit for Supplement 9 belongs to the Water Quality Branch of the Inland Waters Directorate, Environment Canada. This study was not part of the original study program or funded by it. Even though the need for an interpretive water quality study became obvious early in the program, it was not until the final compendium of water quality data for the basin was published early in 1981 (partly financed by the study program) that serious thought could be given to the difficult task of interpreting the data for such a huge and varied area. Fortunately, internal funding was quickly obtained and work began later in 1981, hence the 1983 publication date. The Mackenzie River Basin Committee is pleased that the report nevertheless will form part of the series of Mackenzie River Basin Study Report Supplements.

ACKNOWLEDGEMENTS

The Mackenzie River Basin Committee wishes to acknowledge the assistance and cooperation of the numerous individuals, agencies, university departments, and private consultants who contributed to the Mackenzie River Basin Study.

Special thanks are extended to Dr. S. Zoltai, Northern Forest Research Center, Edmonton, and Mr. P. Lewis, Inuvik Research Laboratory, for reviewing several sections of this report. The Alluvial Ecosystems study was inititated through the efforts of the late Dr. Don Gill, University of Alberta, Edmonton. Dr. J.D. Mollard, Regina, interpreted the LANDSAT images in Chapter 2 and allowed the use of definitions contained in his "Airphoto Interpretation Manual."

Mr. Dwight Quiring was in charge of drafting, layout, and printing arrangements for the report. Mrs. Gwen Maloney typed this report and its numerous drafts. Editorial assistance was provided by Mrs. Virginia Dobson. A list of photo credits can be found at the end of Appendix D.

Complete report sets have been deposited with major libraries throughout Canada. A limited number of copies of the main study report are available in English or French by writing to:

Mackenzie River Basin Study Report
Inland Waters Directorate
Environment Canada
1901 Victoria Avenue
Regina, Saskatchewan
S4P 3R4

A. People and Resources
B. The Basin
C. Drainage Subbasins

Mackenzie River Basin

2

Mackenzie River Basin

Major Lakes, Deltas and Rivers

Lakes	water surface area (km²)
Great Bear Lake	30 800
Great Slave Lake	26 900
Lake Athabasca	7 850
Deltas	**area (km²)**
Mackenzie River Delta	12 000
Peace-Athabasca Delta	6 070
Slave River Delta	385
Rivers	**length (km)**
Mackenzie River	1 650
Peace River	1 650
Athabasca River	1 280
Liard River	1 100
Slave River	415

Drainage Areas

	area (km²)	% of basin
British Columbia	274 500	15.4
Alberta	444 700	24.9
Saskatchewan	134 100	7.5
Northwest Territories	804 200	45.0
Yukon Territory	129 500	7.2
Total	1 787 000	100

Major Communities

		1976 Census Population	1980 Estimated Population
British Columbia	*52 360		
Fort St. John		8 947	12 500
Dawson Creek		10 526	12 120
Fort Nelson		2 816	4 000
Chetwynd		1 487	2 230
Alberta	*190 100		
Fort McMurray		15 424	27 780
Grande Prairie		17 626	22 720
Hinton		6 731	8 020
Peace River		4 840	5 750
Edson		4 038	5 670
Whitecourt		3 878	5 150
Jasper		3 603	3 700
Barrhead		2 944	3 520
Saskatchewan	*3 630		
Uranium City		2 028	2 340
Northwest Territories	*29 600		
Yellowknife		8 256	10 920
Hay River		3 268	3 580
Inuvik		3 116	3 010
Fort Smith		2 288	2 380
Pine Point		1 915	1 840
Rae-Edzo		1 158	1 660
Fort Simpson		1 136	1 100
Yukon Territory	*1 260		
Watson Lake		808	1 370
BASIN POPULATION	**276 950**		

*Approximate populations in each part of the Mackenzie River Basin, 1976.

Figure 2.1
Fact Sheet

"The Mackenzie" is one of the great river systems in the world, the twelfth largest by drainage area and eleventh in mean annual discharge. It is one of the great circumpolar rivers, and North America's largest northflowing river. The basin harbours three major lakes, two significant freshwater deltas, and the world's tenth largest marine delta through which it influences an important arctic area, the Beaufort Sea.

For many people "The Mackenzie" stands for both the majesty and beauty of the land and the river, some of it protected in three national parks. It also represents some exciting Canadian history. John Alexander Mackenzie, after whom the river was named, played a key part in exploring this part of the continent. While looking for the famous Northwest Passage, he opened up the area for the fur trade and claimed the area for the British Crown.

The Mackenzie River Basin is described briefly in the three sections of this chapter. The first section describes the people, the development history, and the resources of the basin. The next two sections describe features of the basin and its subbasins.

A. People and Resources

This section describes the people and resources of the basin and their development. Although there is some discussion of future potential, this theme is developed mainly in Chapter 6.

1. People

The first people to settle the northwest region of North America were the ancestral American Indians, moving from Asia across the Bering Strait as early as 25,000 years ago. They eventually spread to the south and east. Later the Inuit people also moved into this area from Asia, eventually settling the arctic coastal areas and the tundra region north of the tree line.

Until the arrival of the Europeans, the Indians and Inuit of the Mackenzie Basin led a nomadic

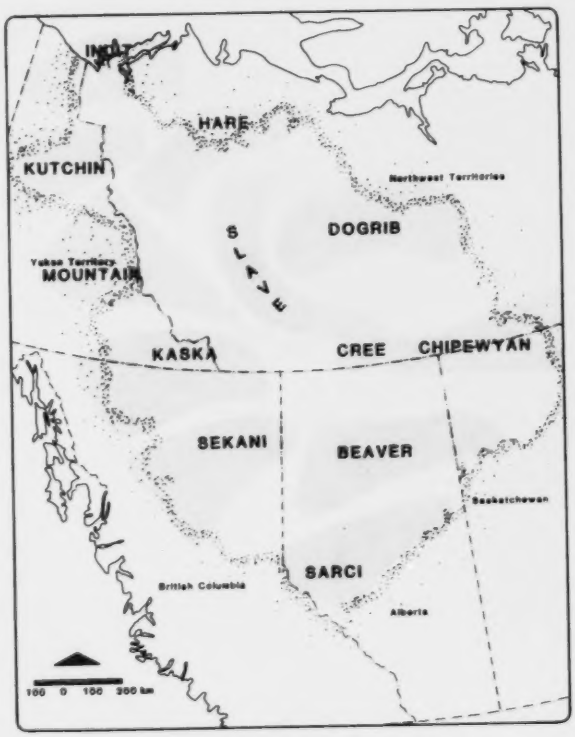


Figure 2.2
Indigenous People

hunting and gathering way of life. The Inuit lived in small family groups in the Mackenzie Delta area and ventured inland only to hunt caribou and muskoxen in summer. There was little cultural exchange or intermarriage between Indian and Inuit groups.

Today the Inuit are still concentrated in the delta area of the Mackenzie River, while the Indians and Metis inhabit all parts of the basin (Figures 2.2 and 2.3). With the exception of Inuktitut spoken by the Inuit, and the Cree language which is Algonkian in origin, all other languages in the basin are Athapaskan. Communication problems caused by the greater mobility of people within the basin are eased by using the English language.

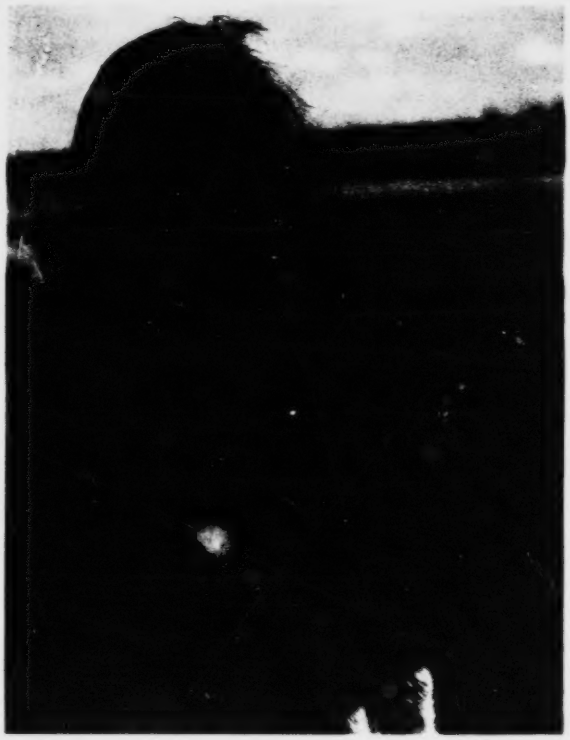


Figure 2.3
Dene Child

Population Over a quarter of a million people of various ethnic backgrounds now live and work in the Mackenzie Basin (Figure 2.1). Nearly 90% live in the Peace and Athabasca regions of northeastern British Columbia and northern Alberta. The vastness of the area and the population sparseness are distinguishing features of the basin. This is particularly true for the area north of 60° latitude in the Yukon and Northwest Territories, as well as northern Saskatchewan (Figure 2.4).

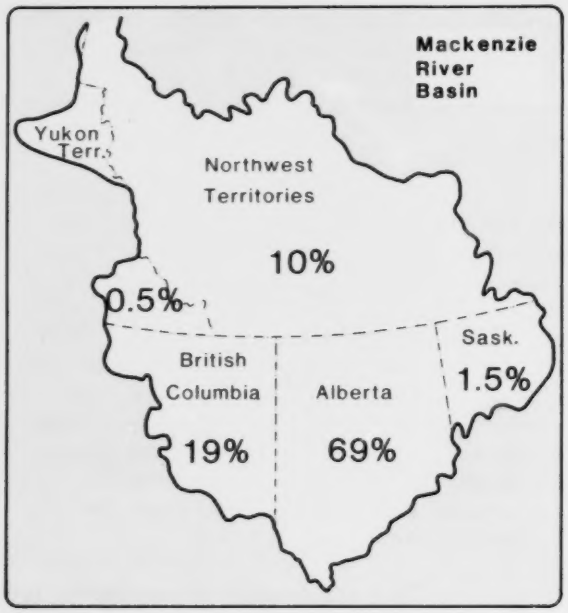


Figure 2.4
Population Distribution

This population sparseness has many social and economic implications, particularly the provision of services to people, even though the majority of basin residents now live in the 24 major communities. There are also a number of smaller communities in the portion of the basin north of 60° whose populations are primarily indigenous people (Table 2.1).

Table 2.1

Small Communities North of 60°

Community	Estimated 1980 Population
Fort McPherson	810
Tuktoyaktuk	800
Aklavik	800
Fort Providence	600
Fort Good Hope	540
Fort Resolution	510
Fort Franklin	510
Tungsten	500
Norman Wells	400
Fort Liard	360
Fort Norman	300
Snowdrift	260
Lac la Martre	230
Rae Lakes	180
Wrigley	120
Nahanni Butte	90
Colville Lake	70
Trout Lake	60
Jean Marie River	50
Enterprise	40
Kakisa	40

One of the area's attractions for many people is the solitude of the wilderness areas, and the opportunity to combine modern and traditional lifestyles. Obviously this is less so in the southernmost part of the basin which is only 50 km north of the Edmonton metropolitan area (with half a million inhabitants). Within the basin the wilderness experience is probably shaped more by rivers and lakes than by any other feature of the landscape. Many residents spend a large part of the summer months travelling on the water or fishing. In winter, these water bodies serve as ice roads for travel thoughout the basin. An increasing number of urban dwellers have camps and cottages along nearby rivers and lakes.

Early Development The first encounters between natives and Europeans occurred during the 16th to 18th Centuries, when explorers such as Alexander Mackenzie and Samuel Hearne entered the area. Some Europeans explored independently, but many worked for either the North West Company or the Hudson's Bay Company, which were fierce rivals until they amalgamated under the latter's name by royal decree in 1821. This amalgamation was a goal Alexander Mackenzie pursued zealously in his later years, hoping to protect British interests against American and Russian encroachments.

By the late 1800's the fur trade had become focused in the Mackenzie Valley, and settlements grew up around trading posts along the major waterways. The Indians and Inuit began to abandon their traditional nomadic lifestyle and settle near the trading posts and missions. The Northwest Mounted Police eventually extended the country's law system to the north.

Recent Development There was a large influx of non-native people who came to the basin with the discovery of oil at Norman Wells in the 1920's and the mineral

Figure 2.5

Contrast in Transportation

discoveries at Great Bear and Great Slave Lakes in the 1930's. The Second World War precipitated the building of the Alaska Highway and several airfields. Airplanes opened up formerly remote and inaccessible areas and brought the basin into the 20th Century (Figure 2.5). The discovery of uranium at Great Bear Lake as well as base metal and gold deposits near Great Slave Lake attracted more people to the middle part of the basin. By the 1950's the Mackenzie Highway was extended to Yellowknife (Figure 2.6) and Fort Simpson. This was the beginning of a trunk road system which was greatly expanded during the 1960's and 1970's. The Dempster Highway from the Yukon Territory to Inuvik was completed in 1979. The only extension since that time has been the Liard Highway which will be completed in 1983.

Water Transportation

Rivers and lakes were the key to the early exploration and settlement of the basin. People depended on them for their livelihood and for travel, be it in the winter or the open-water season. During the freezeup and breakup periods, when river travel was not possible, life was seriously affected if this period was lengthy.

The fur trade in the 19th Century depended on river transportation, first by freighter canoe and later by barge. The Hudson's Bay Company expanded from fur to a much wider trade and gave the basin's economic development a significant impetus by establishing the Mackenzie River Transport Company and providing a regular shipping service.

Woodburning paddlewheelers served the early trading posts, missions, and government stations before the discovery of oil at Norman Wells and the discovery of gold, radium, and pitchblende at Great Bear Lake in the 1920's and 1930's.

Figure 2.6
Yellowknife
Capital of the Northwest Territories

Northern Waterways Limited began the first full service in 1931 with one wooden vessel and two barges from Waterways, Alberta (near today's Fort McMurray) to Aklavik. The company changed its name to Northern Transportation Company Limited (NTCL) in 1933 and came under Crown ownership during the Second World War. In 1957 NTCL bought the Mackenzie River Transport Company and became the main shipper of bulk loads and heavy equipment on the Mackenzie River. A barge service operates from early June to late October from the Town of Hay River to the Arctic Ocean (Figure 2.7). Other smaller carriers, including Kaps Transport, are also licensed for commercial hauling on the Mackenzie River.

To this day there is a critical period in the spring when many communities and industries anxiously watch their depleting supplies before the first barge shipment arrives. There is an equally critical period in the fall when shippers race against freezeup to deliver the last shipment of winter supplies. The basin continues to rely heavily on river transportation, although there is no longer an absolute dependence because of ubiquitous air transportation and improved highway access in some areas.

Figure 2.7
Mackenzie River Barge Traffic

2. Resources

The Mackenzie Basin has a modern economy, although there are great differences between the southern and northern parts of the basin. For example, some basin residents, particularly in the northern areas, still hunt and fish for food or to supplement their incomes. The southern areas are very much a part of their respective provincial economy, particularly through hydroelectric power and oil and gas production. This economic linkage will extend to the entire Mackenzie Valley as the basin develops.

A brief description of the basin's main resources follows.

Surface Water Water is as important to the modern economy developing in the basin as it has been to its traditional economy. For most industries and communities water is an essential commodity. There is, therefore, a great awareness that water is an important resource which can be adversely affected by major developments such as exploration for and production of oil, gas, and minerals; construction of highways and pipelines; and river dredging for improved navigation. Environmental assessment requirements and regulations now in effect recognize this fact, but their usefulness depends on a sound data base and a thorough understanding of the water system and associated resources. The

surface water resources are described more fully in Sections B and C of this chapter.

Groundwater Groundwater is an important component of the hydrologic cycle and will become increasingly important in the Mackenzie River Basin. Very little is known about it, but it was beyond the scope of this study program to investigate groundwater. This report therefore deals only with the surface water resources of the basin.

Mackenzie Waterway The Mackenzie River, extending from Great Slave Lake to the Beaufort Sea, is the mainstay for moving commodities and supplies to northern communities and will continue to provide the most economic and practical means of transporting heavy equipment and construction materials for industrial development in the north. The basin contains some 3800 km of scheduled shipping routes and gives access to another 2500 km of coastal shipping. Over the last five years freight tonnage has averaged about 320 000 tonnes.

Because of the shallow water and numerous rapids in the river, the design capacity of the barge fleet is seldom if ever achieved, even during high water periods. Subject to runoff conditions from the major tributaries into the Mackenzie, minimum water depths may vary from 1.2 m to 2.4 m depending on location and time of year. The most critical rapids and shallow sections for navigation are the following:

- Beaver Lake. The water depth in the navigation channel is in the order of 1.5 m to 2.4 m.
- Providence Rapids. Most of the channel is deep, but is limited in one shoal area to a depth of 1.3 m. The current is about 10 km/h or more.
- Green Island Rapids. The navigation channel is narrow, 75 m in width, and has a strong current of 10 km/h.
- Blackwater. For several miles the current is strong and turbulent, about 10 to 13 km/h.
- Sans Sault Rapids. At low stages, the rapids contain numerous eddies with limiting water depths of 1.2 to 2.4 m. Large boulders make navigation hazardous.
- Ramparts Rapids. These rapids are formed by a series of limestone ledges. During periods of low water a distinct drop forms over a distance of about 460 m through which the current flows 10 to 12 km/h.
- Fort Good Hope. The channel downstream contains numerous islands and shifting sandbars, but does not present serious problems to navigation.

Although the rock-formed rapids of the Sans Sault are the most difficult and dangerous to navigate, the first three sections mentioned above really determine the permissible loading of the barges, and thereby the carrying capacity of the river.

The efficiency of the barge operations is also seriously affected by the need to break up tows in order to relay single barges through the difficult reaches. This requires considerable time and effort.

The federal Department of Public Works completed a major survey of the river in 1976, to enable accurate cost estimates of further channel improvements, such as widening the turns, straightening out bends, and deepening the channel to 2.4 m. An environmental review and assessment of this dredging program was later carried out and published in 1978.

In view of the extremely low water levels during the period 1978-80 and resultant restrictions on barge loadings, representations have been made to the federal government to update the cost estimate of this dredging program and reconsider its implementation. In addition, concern has been expressed by navigation interests about the possible effects on river levels and flows of various proposed hydroelectric power developments in the basin.

Hydroelectric Power One of the oldest and most dramatic uses of water is its storage behind large dams and its subsequent release for the production of hydroelectric power. Several such projects have been developed, and other potential projects are being considered (Figure 6.1). There is now a much better appreciation of the previously unknown and sometimes undesirable effects of such developments. Therefore, environmental aspects are among the first to be considered in the advance planning of the projects now being studied on the Peace and Slave Rivers by Alberta Environment, and on the Liard River by the British Columbia Hydro and Power Authority.

The Mackenzie River itself has development potential of 14 000 MW(megawatts), which is more than the present installed hydroelectric capacity west of Ontario. There is additional hydroelectric potential on the Peace, Great Bear, and Slave Rivers, and several others.

It is important to note that the combined effects of several major projects can be substantial. These combined effects can be distant in space and time from the actual construction and can be modified by a chain of causes and effects that are usually difficult to ascertain. This requires a much broader and more comprehensive approach to impact studies than that required for individual projects or smaller basins. These implications are considered in Chapter 6.

Oil and Gas Alberta produces 85% of Canada's oil and gas. An increasingly larger proportion of this production comes from the Mackenzie Basin section of the province. But by far the greatest potential lies in the heavy oil and tar sand deposits in the Athabasca, Peace, and Wabasca River areas (Figure 2.8). These reserves are estimated to be several times as big as Alberta's conventional oil fields.

Development of these vast reserves will require large quantities of water and will also affect the water quality. Because of these and other concerns, the Governments of Canada and Alberta initiated the Oil Sands Environmental Research Program in 1975, concurrent with the start of production from the Athabasca oil sands. The program has been continued by Alberta since the withdrawal of the federal government in 1979.

Almost all of British Columbia's oil and gas production originates in its portion of the Mackenzie Basin. Production from this area amounted to about 2.5% of Canada's crude oil production in 1978, and about 13% of Canada's natural gas production.

Production in the territorial parts of the basin include oil at Norman Wells and a gas field at Pointed Mountain. There are non-producing gas fields in the Mackenzie Delta and the Kotaneelee gas field in the Yukon. Extensive exploration continues, primarily in the Beaufort Sea area. If Beaufort Sea development proceeded, the Mackenzie Delta would be the most directly affected area; however, the economic effects would be felt along the entire Mackenzie Valley.

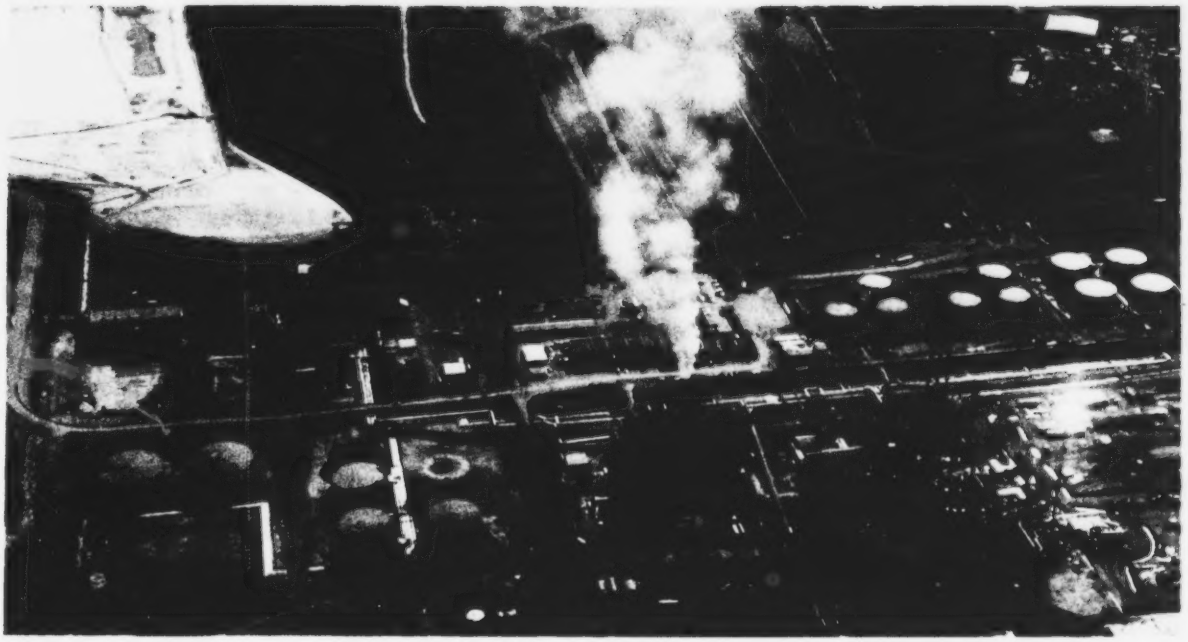


Figure 2.8
Great Canadian Oil Sands Plant
Fort McMurray, Alberta

Mining Mining in the basin dates back to the 1920's and now includes coal, gold, silver, copper, tungsten, cadmium, asbestos, lead, zinc, and uranium. Coal mining is concentrated in Alberta's portion of the basin, although negotiations are underway for development of British Columbia's huge Northeast Coal Block. British Columbia also produces copper and asbestos. Saskatchewan produces mainly uranium in its part of the basin.

There is considerable mining activity in the Northwest Territories portion of the basin (Table 2.2). The Canada Tungsten mine situated on the Flat River in the Nahanni area is the only tungsten mine in Canada. It produced about 6% of the world's supply in 1980. The lead-zinc mine at Pine Point, about 13 km south of Great Slave Lake, brought the railroad north of 60° latitude in 1964. This mine played a crucial role in developing Hay River as a major transfer point and improved the transportation system of the Mackenzie Valley. The mine itself is one of the largest open pit mines in Canada. Gold, silver, copper, and lead are the other main minerals produced in the Northwest Territories.

Agriculture There are about 15 500 farms and 1.1 million hectares of farmland in the Peace River and Athabasca River areas of the basin. About 84% of this land (13 800) farms is located in Alberta, and the remaining 16% (1700 farms) in British Columbia. Less than a thousand hectares are irrigated. Mixed farming and wheat production predominate, although barley, hay, and rapeseed are also grown. In addition, there is livestock production in the Athabasca River area. There is no

Table 2.2

Mining Activities in the Northwest Territories

Company	Location of Mine	Principal Minerals	Approximate Number of Direct Employees
Canada Tungsten Mining Corp.	Tungsten	tungsten	200
Cominco Ltd.	Yellowknife	gold	300
Giant Yellowknife Mines Limited	Yellowknife	gold	340
Pine Point Mines Ltd.	Pine Point	zinc, lead	600
Echo Bay Mines Ltd.	Port Radium	silver, copper	200
Terra Mining and Exploration Ltd.	Port Radium	silver	70

farmland in the Saskatchewan portion of the basin.

Contrary to southern impressions of the north, there is both arable land and farming north of 60°. Although the farms are smaller in scale than farms in the south they are significant to the people of the north. The main commercial agricultural operations are located around Hay River and Mills Lake, where there are market gardens and some .small-scale rapeseed farms. Non-commercial activities have included mission gardens at Fort Good Hope, Fort Simpson, and Nahanni Butte. Outdoor gardens can be found as far north as Inuvik.

However, in most of the Mackenzie Valley north of 60° commercial agriculture is not practical, due to low precipitation, paucity of good soil, and too few frostfree days. Consequently, the Department of Indian Affairs and Northern Development, in consultation with the Governments of the Northwest Territories and the Yukon Territory, has not permitted clearing of new land for agricultural development since 1975. This allowed resource inventories to be carried out south of Great Slave Lake and enabled the territorial governments to start development of agricultural policies.

Forests The forest resources in the southern areas of the basin represent great potential; however, access and transportation costs hinder attempts to utilize even a small portion of the sustained allowable cut.

The main commercial species in British Columbia and Alberta are white spruce, black spruce, lodgepole pine, aspen, and hemlock. The major processing plant in British Columbia's part of the basin is British Columbia Forest Products Ltd. located near Grande Cache. In the Alberta portion of the basin the major plants are Proctor and Gamble Cellulose Ltd. and North Canadian Forest Industries located near Grande Prairie (Figure

2.9), Simpson Timber Ltd. near Whitecourt, and St. Regis Ltd. near Hinton. No estimate for the amount of commercial timber is available for the Saskatchewan portion of the basin. The main species found there are spruce and jack pine.

In the Northwest Territories part of the basin, the major forest resource lies in the Slave River and Liard River lowlands. White spruce is the main species harvested. Most of it is used for lumber, roundwood, and wood for fuel. A major sawmill, Slave River Sawmill, is located at Fort Resolution. In the Yukon part of the basin, white spruce is the major commercial species and the upper Liard River valley is the main production area. This entire region has been leased to Yukon Forest Products.

Fish The species most harvested among the 34 species identified are whitefish, inconnu, northern pike, pickerel, grayling, and lake trout. Domestic fishing which provides a source of food to native people throughout the year is usually carried out by gill netting.

Commercial fishing is important throughout the Mackenzie Basin. Lakes in the basin support 160 commercial operations with the most significant fisheries on Great Slave Lake and Lake Athabasca. Although no

Figure 2.9
Pulp Mill
Grande Prairie, Alberta

commercial fisheries exist on Great Bear Lake, it is a significant sport fishing area.

Fur Hunting and trapping are important economic activities of native people in the basin. The value of the local fur trade fluctuates widely from year to year, usually in response to the population cycle of furbearers and the market conditions. Although a variety of fur bearing animals are trapped, the five leading species are muskrat, beaver, marten, mink, and lynx. Muskrat is the most important species in the lower Mackenzie region, beaver and marten in the central and upper Mackenzie regions, and squirrel and muskrat in the Alberta portion.

Some activity takes place on the traplines in early winter and midwinter, but the most intensive trapping occurs in late winter and early spring. Trappers generally confine themselves to river valleys and lowlands near their settlements. Therefore, there is little overlapping of trapping areas, except for a few overlaps in the Mackenzie Delta, Peace-Athabasca Delta, and the southern portion of the basin in Alberta.

Game Moose, caribou, hare, and waterfowl are an important source of food for the native population of the basin. Only a small quantity of meat is bartered or sold by individual hunters and trappers since game is harvested primarily to meet their own needs. Organized caribou hunts supplement individual efforts.

People still use the hides of moose, caribou, grizzly bear, black bear, and polar bear for clothing materials and other domestic needs, as well as for sale and for hand crafts. Wolf and wolverine, the most sought after furs for trimming parkas, have recently been in short supply and, therefore, are even more valuable than usual.

Game also has considerable economic importance because of sport hunting, and is discussed in the following section on tourism and recreation.

Tourism and Recreation The Mackenzie Basin offers a great variety of landscapes and facilities for tourism and recreation. There are three national parks in the basin and many provincial, regional, and territorial parks. There are lakes, rivers, deltas, rapids, and waterfalls; mixed forests; sand dunes; and tundra. The terrain ranges from the Rocky Mountains and rolling countryside in the west and south, to the rocky Precambrian Shield in the east, and barren lands in the north.

The Alberta portion of the basin offers the greatest choice of recreational environs. Since it is the most populated and accessible part of the basin, it also has the most

Figure 2.10
Canoeing
Athabasca River

facilities; therefore, tourism and recreation play a greater role there. Jasper National Park, for example, attracts international visitors as well as visitors from the Edmonton area which is only 300 km away and serviced by a good year-round highway. Recreational pursuits include fishing in lakes and streams, big game hunting, canoeing, camping, mountain climbing, and skiing (Figure 2.10).

Recreation in the British Columbia portion of the basin is limited to areas near the few access roads such as the Alaska and Liard Highways. Activities include fishing the numerous rivers, streams, and lakes that these roads traverse or approach; camping in the numerous excellent campsites; and hunting in the fall. White-water canoeing is popular in swift flowing rivers.

Hunting and fly-in fishing are the main recreation activities in the Saskatchewan portion of the basin (Figure 2.11).

Wood Buffalo National Park, straddling the Alberta and Northwest Territories boundary, is one of the largest national parks in the world and supports the largest herd of free roaming bison in North America. Nahanni National Park, in the Northwest Territories, was created in 1972 and seven years later was designated as a UNESCO World Heritage Site.

In the area north of 60°, sightseeing, photography, hunting, and fishing are the major tourist activities. Big game hunting in the Mackenzie Mountains opened in 1965. The main species hunted are Dall's sheep, grizzly bear, moose, and mountain goat. Excellent catches of sport fish are common during the summer months. Access to fishing areas is usually limited to rivers and lakes situated near highways or fly-in camps. The more productive locations can be reached only by float aircraft, boats, or pack horses. The most common angling species are northern pike, walleye, lake trout, arctic char, arctic grayling, and whitefish.

Figure 2.11
Sport Fishing
Fond du Lac River

B. The Basin

This section describes the physical features of the basin, its climate, vegetation, water quality, and sensitive areas. The rivers and lakes are described further in Section C of this chapter under the appropriate subbasin.

1. River System

The Mackenzie River system consists of seven major rivers,

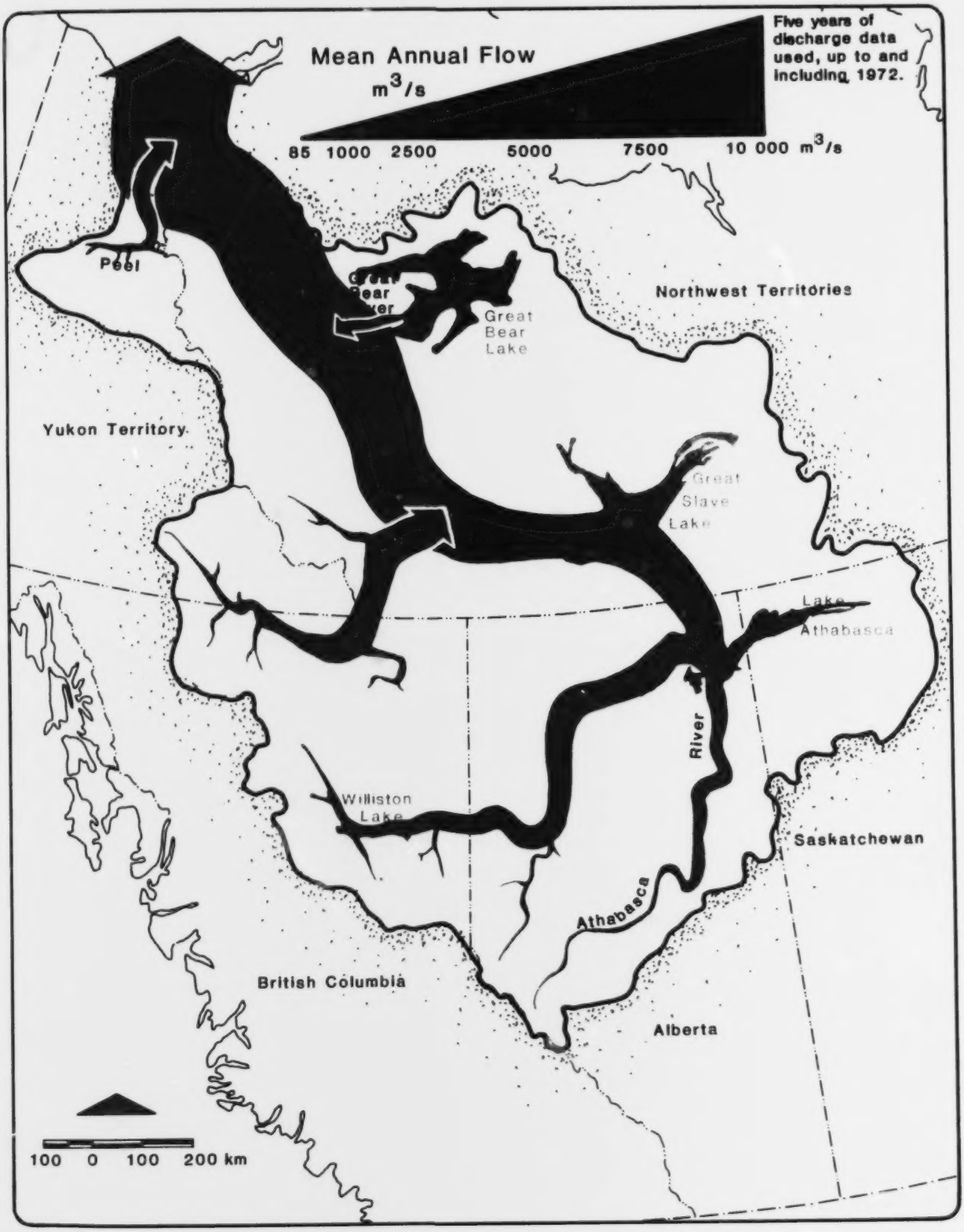


Figure 2.12

Mackenzie River System

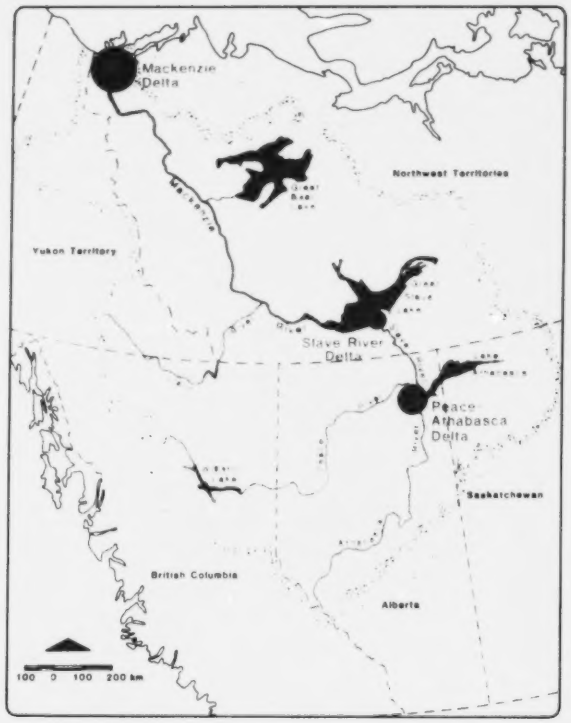


Figure 2.13
Major Deltas

three major lakes (Figure 2.12), and three major deltas (Figure 2.13). It starts with the Peace and Athabasca Rivers in the south, which can be visualized as the two "tails" of the system. They join at the Peace-Athabasca Delta, which is also the outlet of Lake Athabasca, and continue northward as the Slave River, which enters Great Slave Lake through the Slave River Delta. Before these waters flow from the western end of Great Slave Lake, where the mainstem Mackenzie River begins, the two deltas and lakes have cleansed them of sediments and smoothed out the flow (Figure 2.14) and temperature variations.

The Mackenzie River is first joined by the powerful Liard River. For miles downstream the relatively warm and silty Liard River and the cold, clear Mackenzie River can be distinguished visually. This separation is so pronounced that the community of Fort Simpson taps the clear water of the upper Mackenzie for its water supply by means of an underwater pipeline (Figure 4.7). The Mackenzie then flows almost due north and is joined by many rivers, including the Great Bear, Arctic Red, and Peel Rivers, before it reaches the Mackenzie Delta, 1410 km downstream from Great Slave Lake. It then flows 240 km through the delta before emptying into the Beaufort Sea. Figure 2.12 also shows that the biggest contribution by far comes from the western tributaries, while the eastern tributaries off the Precambrian Shield make a much smaller contribution.

The major rivers of the Mackenzie Basin are generally wide and moderately fast flowing. Some reaches of the Peace River have well-defined

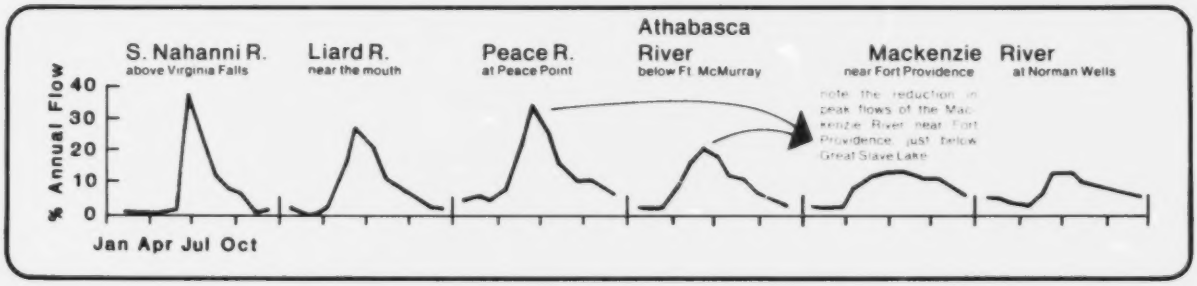
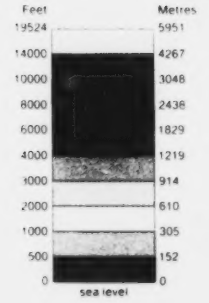
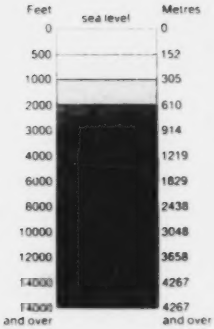


Figure 2.14
Monthly Distribution of River Flows

RELIEF

Mackenzie River Basin





Boundary undemarcated .....

Lake depths are shown in reference to lake level rather than sea level

Scale: 1:10,000,000 or One Inch to 157.82 miles

50 0 50 100 150 200 250 300 350 Kilometres

50 0 50 100 150 200 250 Miles

Lambert Conformal Conic Projection Standard Parallels 49°N and 77°N
Modified Polyconic Projection north of Latitude 80°

Figure 2.15

Mackenzie River Basin Relief

130
110
Amundsen Gulf
Prince Albert Sound
Coronation Gulf
Dolphin and Union Strait
Dease Strait
Larsen Sound
Great Bear Lake
Great Slave Lake
NORTHWEST TERRITORIES
SASKATCHEWAN
Mackenzie River
Liverpool Bay
Richards Bay
Simpson Bay
Melbourne
Queen
Maud
Gateshead
Thunder Bay
Mimy Inlet
Wholdaia Lake
Athabasca
Churchill
Bank
Moresby
Garden
Carlisle
Island

meanders and oxbows, while the Athabasca, Slave, and Mackenzie Rivers are all comparatively straight. The existence of three deltas attests to the large amount of sediment carried by them.

2. Lakes

Great Bear and Great Slave Lakes and Lake Athabasca are three of the world's subarctic great lakes (the other is Lake Baikal in Siberia). They are Canada's third, fourth, and eighth largest lakes and play a very important role in the hydrologic system of the basin (Figure 2.12). Therefore, a brief discussion follows on the processes governing the life of a lake.

Lakes are essential components of the hydrologic cycle. They collect runoff from large tracts of land, store the water for a time, lose some of it to the atmosphere by evaporation, and allow only a certain portion to drain seaward. In this way, lakes even out the flow and temperature variations in rivers as mentioned in the previous section (Figure 2.14). Lakes also affect local climate by the evaporation and by their ability to store heat during warm periods and to release it gradually during cool periods.

Lakes are temporary bodies of water, geologically speaking, regardless of origin or size. The inflowing water brings with it eroded material from upstream areas, along with chemicals and nutrients dissolved from rocks and soil, which gradually change the characteristics of the lake quality. The rate at which this occurs depends on the resistance and solubility of the earth and rock upstream. Most lakes begin with water that is cold, clear, soft, low in nutrients, and high in oxygen. These are the characteristics of the three major lakes in the Mackenzie Basin and they are discussed below.

Great Slave and Great Bear Lakes are deep, and since a smaller part of their volume is exposed to heat exchange with the atmosphere (than is the case with a shallower body of water like Lake Athabasca) they are very cold. However, bottom temperatures in all three lakes remain constant at 4°C, the temperature at which water reaches its greatest density.

Almost all of the lakes in the Mackenzie Basin are oligotrophic, or low in primary productivity. That is, they have low nutrient contents (such as phosphates and nitrates) and therefore cannot sustain much phytoplankton. These minute aquatic plants are one of the highly efficient means nature has for converting the sun's energy by photosynthesis into food. Low biological activity, in turn, means that there is little demand for dissolved oxygen. The major lakes, already high in oxygen content because of their cold temperatures (among other reasons), are therefore able to maintain their surface waters consistently at or near saturation, and even their deepest parts at over 80% saturation.

3. Land

The Mackenzie Basin can best be visualized by looking at a relief map (Figure 2.15). This distinctly shows the Rocky Mountains in the west (Western Cordillera), the Mackenzie Valley in the centre (Interior Plain), the Precambrian Shield in the east, and the Mackenzie Delta in the north (Arctic Coastal Plain). The river profiles in Section C of this chapter are also helpful in visualizing the basin's terrain. What they show is today's landscape, the result of innumerable combinations of geologic, climatic, and biologic processes over millions of years.

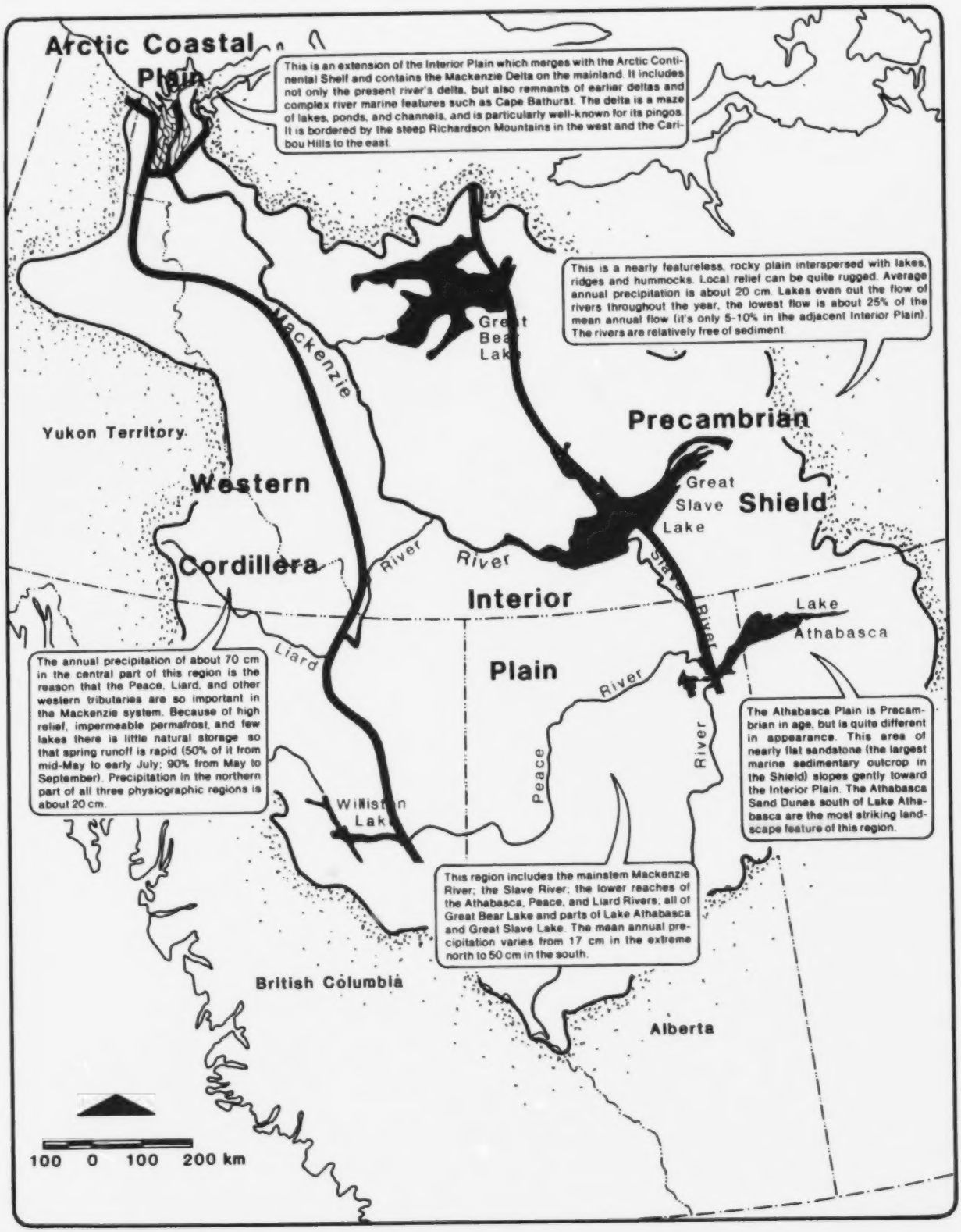

Arctic Coastal Plain
This is an extension of the Interior Plain which merges with the Arctic Continental Shelf and contains the Mackenzie Delta on the mainland. It includes not only the present river's delta, but also remnants of earlier deltas and complex river marine features such as Cape Bathurst. The delta is a maze of lakes, ponds, and channels, and is particularly well-known for its pingos. It is bordered by the steep Richardson Mountains in the west and the Caribou Hills to the east.
This is a nearly featureless, rocky plain interspersed with lakes, ridges and hummocks. Local relief can be quite rugged. Average annual precipitation is about 20 cm. Lakes even out the flow of rivers throughout the year, the lowest flow is about 25% of the mean annual flow (it's only 5-10% in the adjacent Interior Plain). The rivers are relatively free of sediment.
Great Bear Lake
Mackenzie River
Yukon Territory
Precambrian
Shield
Western Cordillera
Great Slave Lake
Slave River
Interior Plain
Lake Athabasca
Liard River
Peace River
Williston Lake
The annual precipitation of about 70 cm in the central part of this region is the reason that the Peace, Liard, and other western tributaries are so important in the Mackenzie system. Because of high relief, impermeable permafrost, and few lakes there is little natural storage so that spring runoff is rapid (50% of it from mid-May to early July; 90% from May to September). Precipitation in the northern part of all three physiographic regions is about 20 cm.
The Athabasca Plain is Precambrian in age, but is quite different in appearance. This area of nearly flat sandstone (the largest marine sedimentary outcrop in the Shield) slopes gently toward the Interior Plain. The Athabasca Sand Dunes south of Lake Athabasca are the most striking landscape feature of this region.
This region includes the mainstem Mackenzie River; the lower reaches of the Athabasca, Peace, and Liard Rivers; all of Great Bear Lake and parts of Lake Athabasca and Great Slave Lake. The mean annual precipitation varies from 17 cm in the extreme north to 50 cm in the south.
British Columbia
Alberta
100 0 100 200 km

Figure 2.16

Physiographic Regions

This huge river system has developed and continues to develop according to a particular set of complex circumstances. The physiographic regions (Figure 2.16) reflect not only the four broad types of relief mentioned earlier, but also the basin's geologic past. Without going into a detailed analysis, three interesting points can be made here:

a. The Mackenzie Valley is part of a much larger interior plain with a complex history of its own. The 24 million tonnes of sediment carried out to the Beaufort Sea daily at the height of the 1974 spring flood proves how powerful a geomorphic agent the Mackenzie River and its tributaries can be.

b. The Shield extends all the way to the Slave River, even though the relief map might suggest that it coincides with the height of land east of the Slave River lowland.

c. The Mackenzie Delta appears as a continuation of the Interior Plain, but is nevertheless quite distinct from it. The delta is the result of a long history of interaction between the Mackenzie River and the Beaufort Sea, and their predecessors in geologic time.

The effect of elevation and relief on precipitation and runoff is illustrated very effectively in the Western Cordillera, which intercept the moist air coming from the Pacific Ocean. As a result the mountain tributaries contribute by far the largest share to the Mackenzie River flow. Contrast this with the Shield which is actually semi-arid, despite the abundance of lakes in the area and the image of a snowbound countryside.

Permafrost In a large part of the basin the ground remains permanently frozen (Figure 2.17). Permafrost forms where the mean annual temperature is below freezing and there is enough moisture in the ground to keep it frozen for long periods. In the MacKenzie Delta it can easily extend 100 m down, and at neighbouring Prudhoe Bay in Alaska is known to be 660 m at its deepest. Permafrost provides a firm footing when the ground is frozen from the surface on down. However, where it is thin or discontinuous, or where the thermal regime is upset by removal of ground cover or by construction, it presents unique problems. The difficulty and cost of building on and working in permafrost soil are well known.

Special mention must be made of the pingos on the Tuktoyaktuk

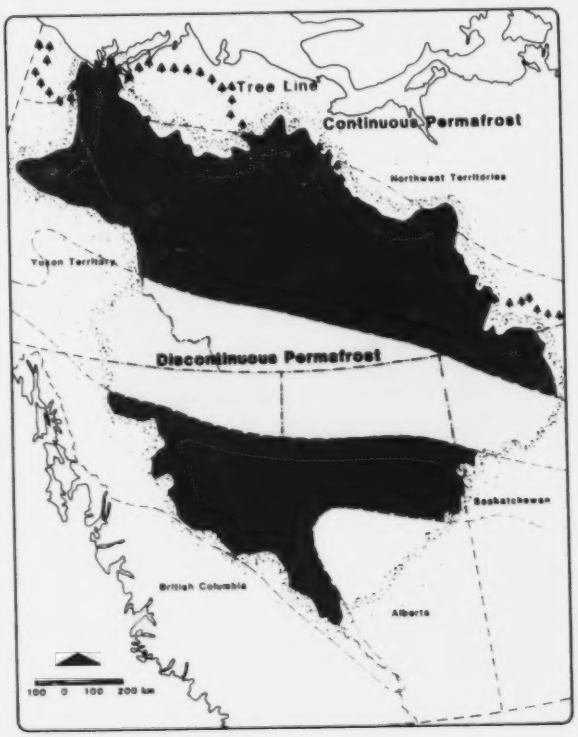


Figure 2.17
Permafrost Zones

Peninsula, which was part of the old Mackenzie Delta but is now just outside it. These massive earth-covered mounds of ice rise abruptly out of the tundra making this one of the most unusual landscapes in Canada. This is one of the areas being considered for protection as a National Landmark.

4. Climate

Climate plays an especially critical role in northern latitudes. The relationships between all life processes (the ecology) and climate are very delicately balanced in the north, and in a large measure involve the rivers, lakes, and water-related habitat. For example, rivers are a prime shaper of land. As rain and snowmelt collect in the tributaries, they erode the land in the process. The sensitivity of these relationships cannot be overemphasized.

The key determinant of climate is the solar energy input, which decreases as latitude increases and becomes critical for the two thirds of the Mackenzie Basin at higher latitudes. At these latitudes the inclination of the sun's rays is lower so that the intensity of solar radiation in northern areas is less than in the south throughout the year. At midsummer the lower intensity is almost fully compensated by the longer days, but in winter it is compounded by the shorter duration of daylight (Figure 2.18).

The climate of the Mackenzie Basin may be divided into two regimes: tundra and subarctic. The tundra climate embraces the north-eastern part of the basin as well as the higher altitudes of the Western Cordillera. The remainder of the basin is subarctic in nature, with low precipitation and cool summers. The Mackenzie Valley itself has a somewhat milder climate than adjacent areas to the east and west.

In the region north of the Arctic Circle (66 1/2°N) there is a period during the winter when the sun is continuously below the horizon. The length of this dark period varies from

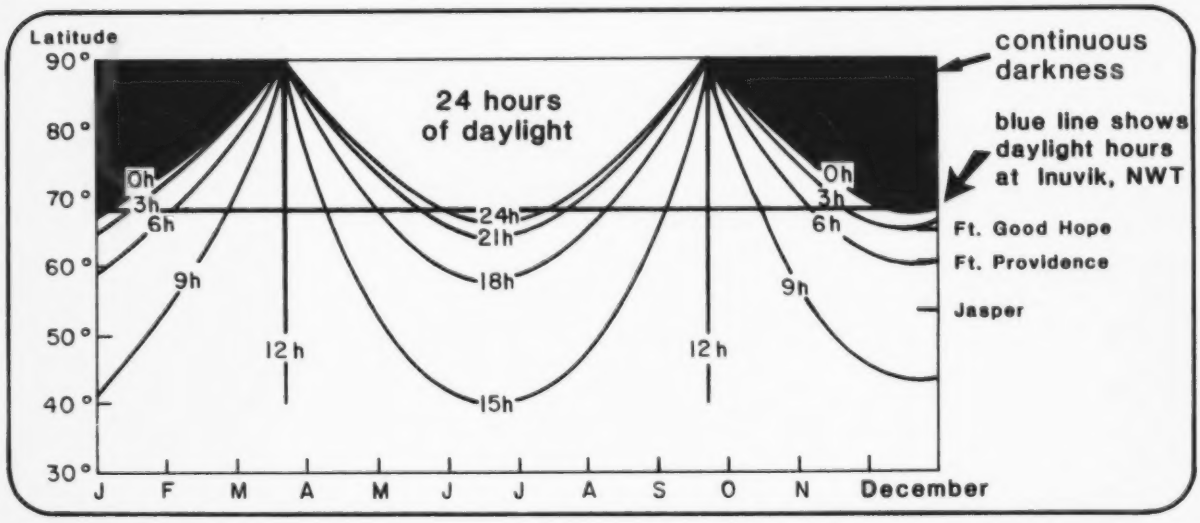


Figure 2.18
Duration of Daylight Hours

one day at the Arctic Circle to six months at the North Pole. Since no direct solar radiation is received during this dark period, the ground radiates heat into space; the air grows colder and denser; and the atmospheric pressure begins to build. The centre of highest pressure usually situates itself over the central Mackenzie Valley. Throughout the winter, surges of cold air flood southward carrying arctic conditions as far south as the Great Plains. Very low temperatures prevail during the winter months in the Mackenzie Basin. With no significant source of heat available, temperatures may drop to -50°C and may recover to only -45°C during the daily twilight period. Spells of intense cold with temperatures below -40°C may last for several weeks at a time, particularly during the months of January and February. The ability of the air to contain moisture at such low temperatures is limited and very little precipitation can fall under such circumstances. Most of the winter's accumulation of snow occurs with injections of milder, moist air aloft from the south or southwest. Even though the mild air may not reach ground level, there is usually some moderation of temperatures.

The southern part of the Mackenzie Basin usually does not endure such long, unbroken spells of clear, cold weather. The more normal pattern of weather consists of brief alterations from cold, clear air to cloudy, moderate air that is periodically drawn across the Cordillera from the Pacific. Typically, such a weather regime gives rise to heavier winter precipitation than can be expected farther north. These changes in contrasting weather patterns are a function of a more disturbed pressure field than is typical farther north. Low pressure systems, originating in the Gulf of Alaska, frequently cross the Rocky Mountains between 50°N and 60°N bringing with them modified air masses from the Pacific Ocean. Their period of influence is brief, though, as the colder air quickly gains southward momentum behind the passing low pressure centres. Strong and shifting winds accompany these major weather changes across Alberta. On occasion, a combination of high winds and loose snow creates heavy blowing snow which can seriously disrupt most means of transportation. Ironically, human discomfort from the cold can be more severe in the southern areas of the basin than in the north because of the wind factor. The strong, cold winds can produce temperature sensations on exposed flesh that exceed (in the negative sense) real temperature values recorded a thousand or more kilometres to the north.

As the sun moves northward in February and March, increasing amounts of heat begin to modify the cold air centre, and slowly the ridge of high pressure begins to erode. As temperatures moderate, increased storminess develops throughout the central and northern Mackenzie Basin and the long winter drought finally breaks. As the spring season advances, the storms move farther north and melting conditions advance northward, down the valley. By June, most of the snow has melted in the northern sections though lake ice may persist until the end of the month.

In the south, the summer season is warm, and convective showers and thundershowers are common. This latter phenomenon does not extend much above 65°N, as the atmosphere tends to be more highly stratified to the north. Near the arctic coast, most summer rains develop around weak lows travelling southeast from the Beaufort Sea, or from stratus or stratocumulus layers drifting onshore from the Arctic Ocean. Rather spectacular temperature changes can occur at this latitude with slight changes in wind direction. A southerly breeze can often carry very warm air northward from the prairies and send temperatures close to 32°C

as far north as Inuvik. A change to a northerly breeze, by sharp contrast, can carry cold air off the arctic ice packs onto the coast and cause a 17C° to 22C° drop in temperature in just a few hours.

With the advance of the autumn season, the sun's rays become more indirect and the air over the northern Mackenzie Basin begins to grow colder again. Interaction between this cold air and the still warm air masses to the south increases the incidence of storms. Eventually the rains turn to snow. Easterly winds circulating around the low pressure systems have a significant vertical component as they are forced to ascend the higher terrain. Upslope flow nearly always enhances the condensation process and results in heavier precipitation regimes in the upland zones. As the arctic air acquires dominance by late December or early January, the weather patterns become more settled and a generally clear, cold regime takes over until spring.

5. Vegetation

The Mackenzie Basin spreads across several vegetation regions (Figure 2.19). The dense forests of the boreal forest region become the open woodlands of the subarctic forest farther north. In the far north, beyond the tree line, the shrubby tundra of the low arctic region dominates. A corresponding pattern of regions is apparent in the mountains, where subalpine woodlands and alpine tundra develop at higher elevations.

The southern part of the boreal forest is dominated by mixed hardwoods and conifers. Aspen stands, often originating after fire or cutting, are slowly invaded by spruce in the mature stands. In areas that have been burned, pines have re-established growth. Lodgepole pine is found in the foothills and jack pine in the plains of these areas. Black spruce and tamarack are restricted to wet peatlands. In the northern part of the boreal forest the hardwoods gradually decrease and are replaced by conifers, especially black spruce. In general, the boreal forest is characterized by closed-canopy forests of tall trees with luxuriant shrub, herb, or moss ground vegetation on appropriate sites.

Farther north the dominant vegetation gradually becomes black spruce on all but the driest soils. The trees are stunted in their growth and are no longer closely spaced, as their crowns form an open canopy. The openess of the tree cover allows the growth of ground lichens and low shrubs. This is the subarctic forest. On especially suitable sites, such as nutrient-rich alluvial soils, elements of the boreal forest still dominate: tall trees of poplar and spruce grow in dense stands. Such stands of tall timber extend to the southern part of the Mackenzie Delta in alluvial flats, in sharp contrast to the stunted open woodlands surrounding them. Jack pine occurs on dry sites, only as far north as the Great Bear River.

The northern tree line has a poorly defined boundary, where a transition zone separates the subarctic forest from the low arctic tundra. In this zone, small patches of tundra are first encountered on low hilltops, but these become larger farther north. Near the northern limit of trees a few stunted struggling spruce remain, usually growing on sheltered, southfacing slopes. The low arctic tundra is characterized by low shrubs, lichens, and mosses on the well-drained sites and by cottongrass-sedge meadows in the more poorly drained areas.

The commercial use of trees is well established in the boreal forest where pulp and timber

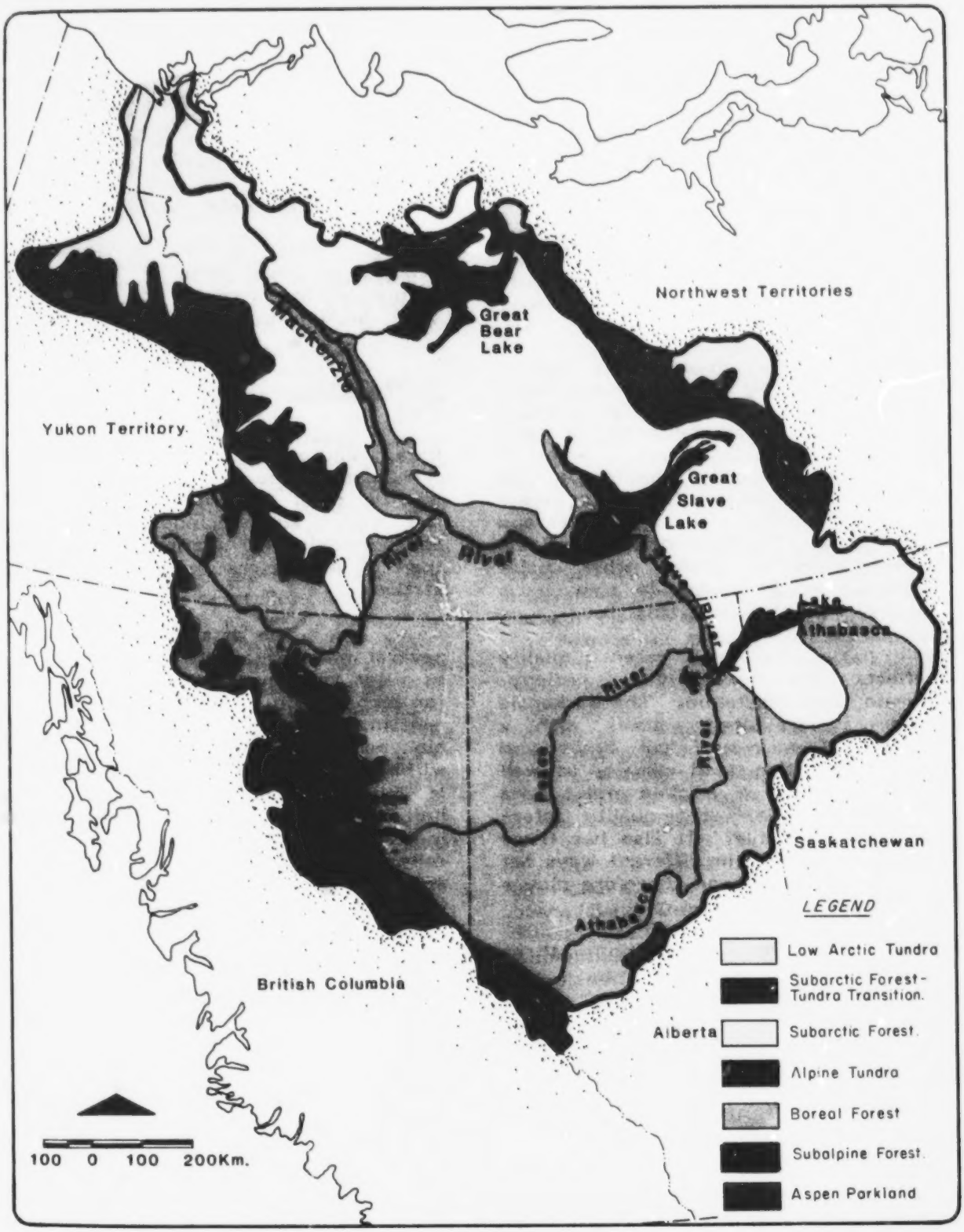


Figure 2.19
Vegetation Regions

industries have been active for decades. The slow growth rate and difficulty in regeneration of cutover areas in the subarctic forest make this region largely unsuitable for commercial exploitation. The large trees in alluvial areas are suitable for poles and piles, but not always for lumber because of the widespread occurrence of spiral grain.

6. Water Quality

Water is the essence of all life forms on earth. Therefore, a sound knowledge of the quality of water in the basin is important. Water in the North basically remains in its natural state, except for water bodies or streams in the vicinity of mines and settlements. The Mackenzie River Basin therefore differs from other major Canadian river basins in that it is virtually unpolluted at this time.

Natural water quality reflects the topography, geology, climate, and vegetation. The Mackenzie River system drains areas with a variety of rock and soil types and ages, vegetation, and climate, as well as a large area of muskeg and tundra for which little water quality information is available. It also has three major lakes which in different ways act as settling basins and therefore play a role in water quality.

The following three factors must be borne in mind:

a. Waters originating from the Shield have a much lower buffering and assimilative capacity against pollution than waters originating from the Interior Plain or the Western Cordillera. It is essential to understand this very important difference, and especially its significance in relation to the types of future development in the basin.

b. Major developments are likely to occur in the basin, particularly metal and hydrocarbon exploration, extraction, processing, and transportation. They have great potential for degrading the quality of northern waters and the delicate biota that depend on good water quality.

c. Water quality is already a problem in some parts of the basin, mainly in the vicinity of mines and some communities.

Water Quality Data — A report containing water quality data, entitled "Water Quality Data, Mackenzie River Basin, 1960-1979," summarizes the historical water quality data currently available for the basin and includes data from approximately 450 stations with more than 40 parameters reported for each station.

The data are presented in several water quality groupings, such as major ions, nutrients, metals, etc., for each station. Each of the subbasin contains a map of the subbasin and an alphabetic listing of the stations within it. In addition, there is a map of the basin, which shows the individual station locations and indicates whether the data were collected by federal or provincial agencies. The report is available from the Publications Office, Inland Waters Directorate, Environment Canada, Ottawa, Ontario, K1A 0E7.

Interpretation — Analysis and interpretation of these data will not be completed until 1982, when the interpretive report on water quality (Supplement 9) will be published. The brief water quality statement below illustrates some of the relationships that are being examined.

The influence of topography on water quality in the Macken-

zie Basin is apparent in the Mackenzie Mountains. Because of the high relief and high rainfall there, the waters of the Arctic Red River which flow through these mountains are typically much more turbid than those that run through the low-relief Precambrian Shield, like the Snare River. It is interesting to note that even though the Shield is semi-arid, the low relief and presence of permafrost (especially in the northeastern part of the basin) produce a myriad of lakes, swamps, and muskeg. Rivers running through these areas of muskeg and swamp are notably more colored than rivers that are not influenced by these surface conditions.

Bedrock affects water quality in two respects: the quantity of dissolved solids and the hardness of water. Two tributaries to Great Bear Lake illustrate the first effect. The Camsell River, which flows into the eastern end of Great Bear Lake after traversing the crystalline bedrock of the Shield, has a lower content of dissolved solids than does the Johnny Hoe River, which flows across the sedimentary rocks of the Interior Plain before emptying into Great Bear Lake. The second effect is illustrated by the Hay and Cree Rivers. Water of the Hay River, which flows across the Interior Plain, contains more calcium than the "soft" water of the Cree River, which flows across the crystalline Precambrian Shield.

Most waters within the basin exhibit a typical freshwater composition. However, in one area near Fort Smith, for example, Bench Mark Creek and Little Buffalo River, the waters are unusually saline with a high content of dissolved solids. This reflects the migration of circulating groundwater and surface leaching in an area of evaporitic formations.

7. Sensitive Areas

There are many biologically productive and culturally or socially valuable areas in the basin which could be affected by changes in the natural conditions of river flow, water quality, or sedimentation. Four studies addressed the issue of sensitive areas:

a. Available information on a number of reportedly sensitive areas was gathered and evaluated. The results are included in the subbasin descriptions of Section C in this chapter. The detailed results are contained in Supplement 1 to this study report.

b. The first comprehensive description of the basin's alluvial ecosystems and their dependence on natural river regimes was produced. The results are summarized in Chapter 3 and described in detail in Supplement 2.

c. Detailed field studies provided baseline data on the Slave River Delta. The results are summarized in Appendix A and described in detail in Supplement 6.

d. Detailed field studies also provided baseline data on the Athabasca Sand Dunes in Saskatchewan. These results are summarized in Appendix B and described in detail in Supplement 7.

A discussion of the four main types of sensitive areas in the Mackenzie Basin follows.

Delta Habitat Deltas are among the most efficient and productive ecosystems in nature, providing life support for diverse plant, fish, waterfowl, and wildlife

populations. Early in man's history the great civilizations developed in delta plains, and now some of the greatest harbours are located in deltas.

The diversity and productivity of deltas depend on periodic flooding and deposition of the nutrient-rich sediment that created the deltas in the first place. Because of the enormous variety in the shape, size, geologic structure, and history of deltas, each delta is a unique natural phenomenon. This is certainly true for the three deltas in this basin. The Slave Delta exhibits the bow shape of a relatively simple delta. The Peace-Athabasca Delta is a complex delta formed by two rivers, each with a different geologic history and hydrologic behaviour. The Mackenzie Delta is of a larger order of magnitude and complexity altogether, and has very special significance because of its northern location and its influence on marine life in the Beaufort Sea and the Arctic Ocean.

Deltas in the north are especially important because alternative productive habitat often does not exist in the surrounding region. Their significance extends to a continental level when considering migratory birds. Four flyways on the North American continent funnel into the Mackenzie Valley, and the birds depend on the three deltas as staging and nesting areas (Figure 2.27).

Non-deltaic Habitat The areas along banks of rivers, streams, and lakes are constantly being created, destroyed, or changed by erosion and sedimentation. They are vital for the maintenance of vegetational communities which provide the most important wildlife habitat in the basin, particularly in permafrost areas. Their existence depends on natural river regimes, with their associated periodic flooding.

Fish Habitat The importance of deltas for fish spawning, rearing, and overwintering has already been mentioned; however, other river areas are also very important. A general characteristic of the basin is that west bank tributaries to the mainstem Mackenzie River have relatively high levels of suspended sediments, while the east bank tributaries draining the Shield contain little sediment. This distinction is important, given the spawning requirements of various species of fish.

Some species such as the arctic grayling, arctic char, lake trout, lake whitefish, and rainbow trout spawn in gravel, and therefore need habitat that does not receive much sedimentation during incubation. Any unusual increases in sedimentation during the spawning period could severely reduce their spawning success.

Perhaps equally important to the fish resource is the preservation of overwintering habitats. Most fish species overwinter in areas of open water or in deep lakes. These areas may be quite limited in size and offer no escape to other parts of the river system. Since the populations are already severely stressed under natural conditions in winter, any further unusual changes in winter flow or quality could result in considerable population losses.

Areas of Scenic, Historic, or Scientific Value Some spectacular waterfalls, wild rivers, hot springs, pingos, archaeological sites, and historic communities in the basin are mentioned in this report. The three national parks in the basin protect some of these areas in perpetuity under the National Parks Act. Some others, like the pingos of the Mackenzie Delta and certain wild rivers, are being considered for protection. There are

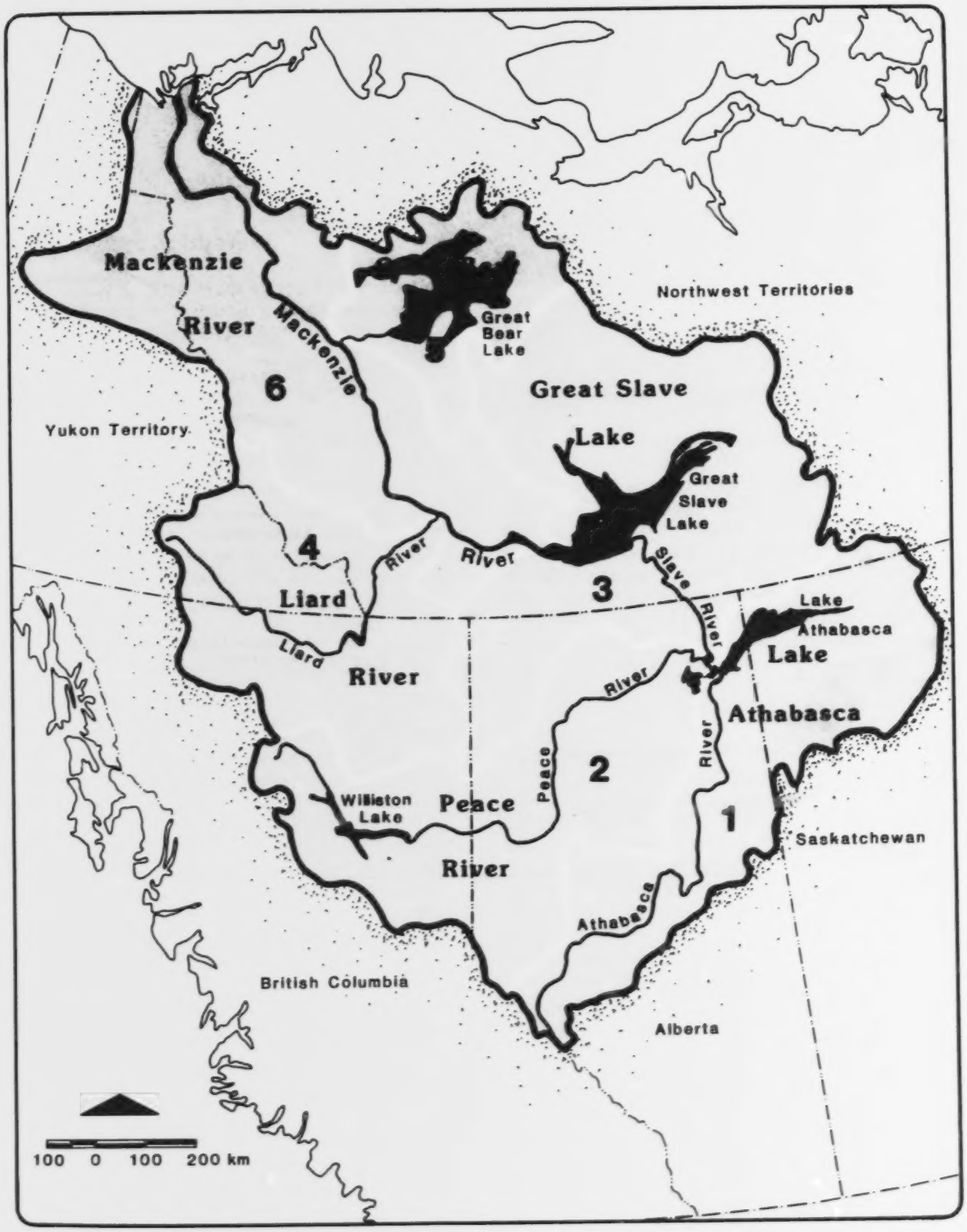


Figure 2.20

Drainage Subbasins

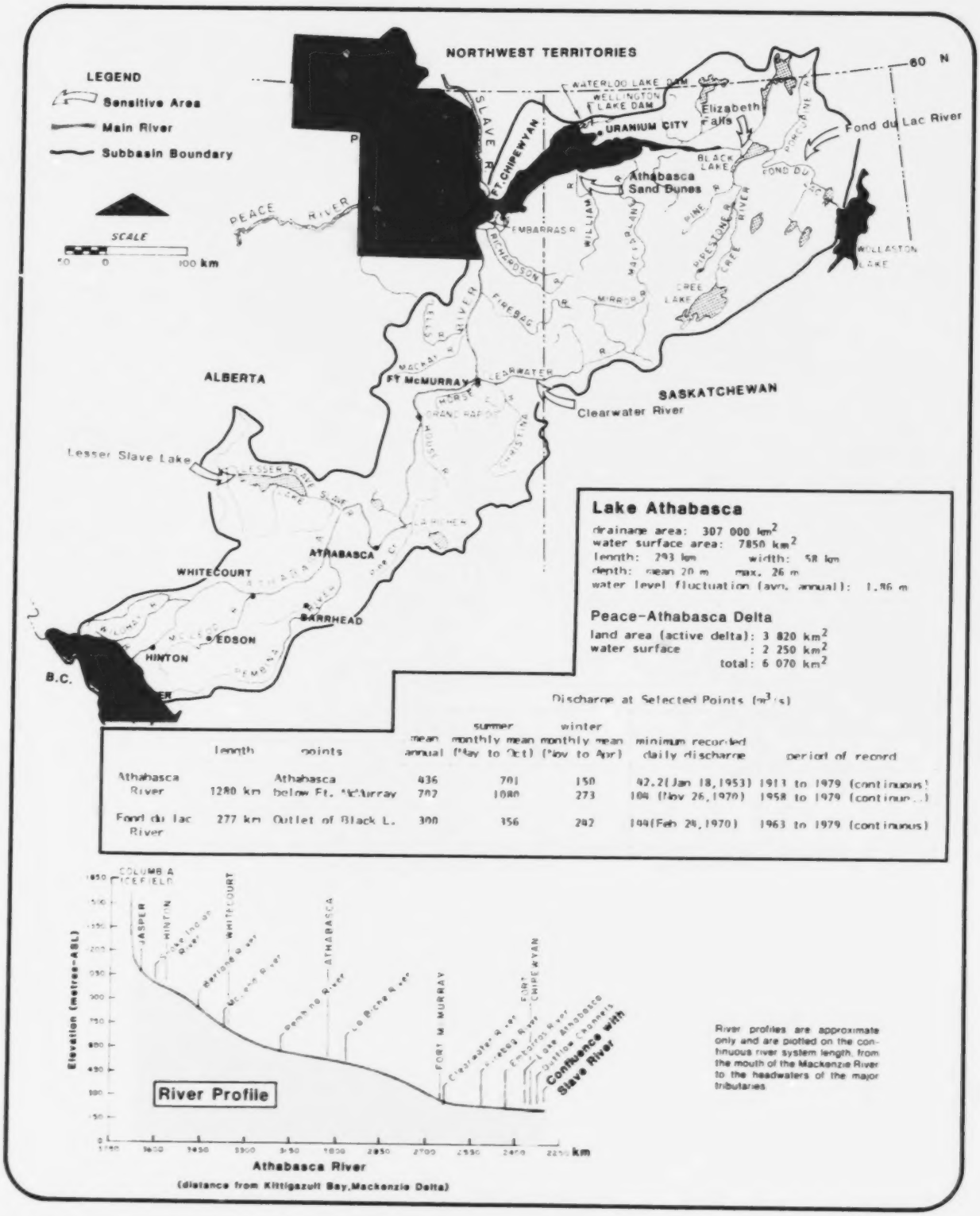


Figure 2.21

Lake Athabasca Subbasin

undoubtedly other distinctive areas that have not been identified yet or are not well known.

C. Drainage Subbasins

The Mackenzie River Basin has six major tributary watersheds or subbasins (Figure 2.20):

1. Lake Athabasca
2. Peace River
3. Great Slave Lake
4. Liard River
5. Great Bear River
6. Mackenzie River.

Each of these subbasins is a large geographic entity of its own and could well be the subject of individual basin planning studies. The purpose of this section is to sketch the essential characteristics of each subbasin and relate these to the rest of the basin.

The facts in each subbasin map were compiled from many sources. River profiles are approximate only and are plotted against the cumulative distance from the mouth of the Mackenzie River. This distance includes not only the river lengths, which were measured on 1:500 000 scale topographic maps, but also the distance across the Peace-Athabasca Delta and Great Slave Lake.

A number of reportedly sensitive areas that could be adversely affected by changes in river regime are shown on the subbasin maps and are described under the respective subbasin. In most cases the available information did not allow a definitive assessment of such sensitivity.

Discussion of the first two subbasins include a summary of spring ice breakup of the Athabasca and Peace Rivers. Breakup of the Liard and Mackenzie Rivers is discussed in Chapter 4.

It is useful to keep the following diagrams in mind when reading the rest of this chapter: the relief of the basin (Figure 2.15) and Figures 2.12, 2.20, and 6.1, which are repeated at the end of the report in convenient foldout format.

1. Lake Athabasca Subbasin

Lake Athabasca has two major tributaries, the Athabasca and Fond du Lac Rivers, and discharges through three channels from the Peace-Athabasca Delta at the western end of the lake (Figures 2.21 and 2.22). These three channels (Chenal des Quatre Fourches, Riviere des Rochers, and Revillon Coupe) flow about 40 km north and join with the Peace River to form the Slave River. Periodically the Peace River also overflows into the delta.

Athabasca River The Athabasca River originates in the Columbia Icefields just east of the Great Divide and is the most southerly of the two great tails of the Mackenzie River system (Figure 2.12). It then flows unregulated through mountain terrain, foothills, and then the high Interior Plain before entering the Peace-Athabasca Delta. Breakup proceeds from south to north. Peak runoff follows the snowmelt in the mountains during June and July, and displays the same "flashy" nature in the upper reaches as is seen in the other Rocky Mountain rivers (Figure 2.14).

In the first 96 km from its source to Jasper, the Athabasca River is a large and steep mountain stream, passing over scenic waterfalls and rapids and through canyons and

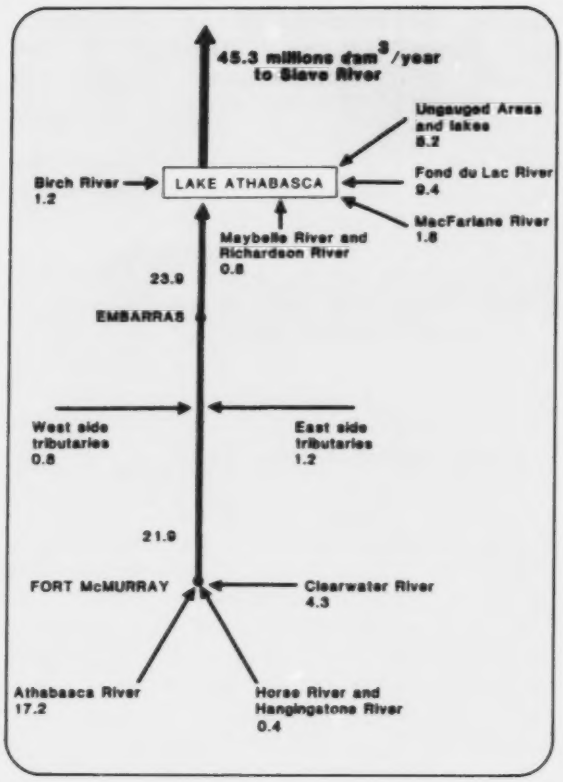


Figure 2.22

Annual Streamflow Balance
Athabasca River

gorges. For 640 km below Jasper the river has a more gentle gradient and follows a northeasterly course across the Alberta Plain. Along the way it is joined by three larger tributaries --the McLeod, Pembina, and Lesser Slave Rivers. The river then assumes a northerly direction and its gradient steepens in a series of rapids, the longest being Grand Rapids. The river proceeds through wilderness for some 380 km before reaching the City of Fort McMurray where it loses the narrow gorge-like character it has maintained since Jasper and is joined by the Clearwater River. Downstream from Fort McMurray the river is deflected north by high bluffs of clay, and takes on a gentle gradient on its way to the Peace-Athabasca Delta.

Athabasca River Spring Breakup

The Athabasca River can be divided into five distinct reaches in which the hydraulic character of the channel and the basin response to snowmelt appear to be sufficiently different to alter the timing and severity of breakup.

The upstream reach of interest extends from Brule Lake to the confluence of the McLeod River. The Water Survey of Canada records for Hinton, extending from 1962 to the present, indicate that the mean date of last ice occurs on April 9, with March 30 the earliest date and April 23 the latest recorded date. It should be noted that the Water Survey of Canada defines the date of last ice as the last day on which ice is judged to affect the rating curve, and therefore is not necessarily the date of breakup. In fact, breakup is generally a few days earlier.

In this reach, the flood levels related to breakup seldom equal the high flood levels experienced during summer floods. This may be explained by the fact that the drainage area above Hinton, Alberta is so small that there is insufficient snowmelt, some of which will be stored in Brule Lake, to generate the large flows required to produce severe ice jams and resulting high water levels. At Hinton the river has a steep channel slope and is confined, resulting in an early failure of the ice sheet. At Windfall, Alberta the breakup levels are reduced because of the split, semi-braided channel which can, even if the main channel is blocked with ice, provide side channels through which much of the flow can pass.

The relatively short reach extending from the mouth of the McLeod River downstream to the mouth of the Pembina River is largely influenced by the snowmelt runoff from the McLeod River watershed. This watershed is

more southerly and at a lower elevation than the upper Athabasca Subbasin and therefore tends to respond more quickly to spring warming. The McLeod River upstream of Whitecourt breaks up an average of three days before the Athabasca River at Windfall, which often results in a large influx of ice into the Athabasca River. Major jams caused flood levels at Whitecourt in 1943 and 1963 which exceeded the 1954 summer flood level of 694 m by three and two metres, respectively.

The breakup of the Athabasca River downstream of the mouth of the Pembina River is controlled by the flow from the Pembina River. An indication of the effects of the Pembina River on breakup can be illustrated by the early mean date of last ice on the Pembina River at Jarvie (April 17). This is five days earlier than the McLeod River at Whitecourt and eight days before the Athabasca River at Windfall.

Downstream of the mouth of the La Biche River the time of breakup deviates from the pattern that follows the warming trends in the southernmost watersheds of the Athabasca River Subbasin. Often the rapids sections break up even when there is only a small increase in discharge. The high channel slope gives rise to large velocities and shear stresses, so that even a small increase in discharge can trigger breakup, while at Athabasca the ice cover remains intact. The rapids sections deteriorate and go out first. This ice moves downstream and accumulates in low velocity areas. As the discharge increases and the ice deteriorates, the small jams move downstream, compound, and alternately move, jam, and build up again. As a result, water levels during the ice run are only slightly lower than peak levels caused by jams.

By the time the ice run reaches Crooked Rapids, approximately 45 km upstream of Fort McMurray, the small jams have consolidated into one large jam often exceeding 25 km in length. When the ice run reaches Fort McMurray it decelerates because of a decrease in channel slope and runs into many islands where it can ground out. The ice may also run into more persistent ice cover associated with the cooler conditions of this part of the Athabasca River Subbasin. When the ice run is stopped, the channel is often filled to the bank with ice. The flood wave that has been pushing the ice run may be forced over the banks. Flooding occurs in the low areas of Fort McMurray when abnormally high river levels on the Clearwater River cause it to back up. The jams can rise to a height of 12 m above the river level and remain until the pressure from the rising water dislodges the jam.

Downstream of Fort McMurray to Lake Athabasca breakup progresses by a succession of ice jams. A more complete description of the Athabasca River spring breakup is found in Supplement 3.

Fond du Lac River The Fond du Lac River is the second largest stream entering Lake Athabasca (Figure 2.22) and has its headwaters in the Precambrian Shield of northern Saskatchewan. Its watershed contains many typical Shield lakes, which produce relatively stable discharges with little seasonal change.

The largest lake in the Fond du Lac watershed is Wollaston Lake which has two outlets. About 10% of the lake outflow enters the Mackenzie drainage by way of the Fond du Lac River and Lake Athabasca. The remainder discharges through the

Cochrane River into the Churchill River drainage system and ultimately into Hudson Bay.

Lake Athabasca This is the most southern of the three great subarctic lakes in the Mackenzie River Basin, and Canada's eighth largest lake. Lake Athabasca is clear and fairly deep, but shallow at the western end where one of the largest inland deltas of the world is situated (Figure 2.23). Barrier islands which formed as a result of wave action in the lake extend from Fort Chipewyan to Old Fort Point. The two lake shores present a striking contrast from the air: the rough and rocky Precambrian Shield terrain to the north, and the bright undulating sand dunes so the south. The explanation lies in geological history.

At the height of the last glaciation the area was covered with up to three kilometres of ice. Raised glacial lake beaches left from the retreating ice abound in the area to the west, and on both shores of Lake Athabasca up to 100 m above the present lake level. As the lakes formed by the retreating ice drained, the newly exposed and unvegetated sediments were subjected to intense wind storms, which formed the sand

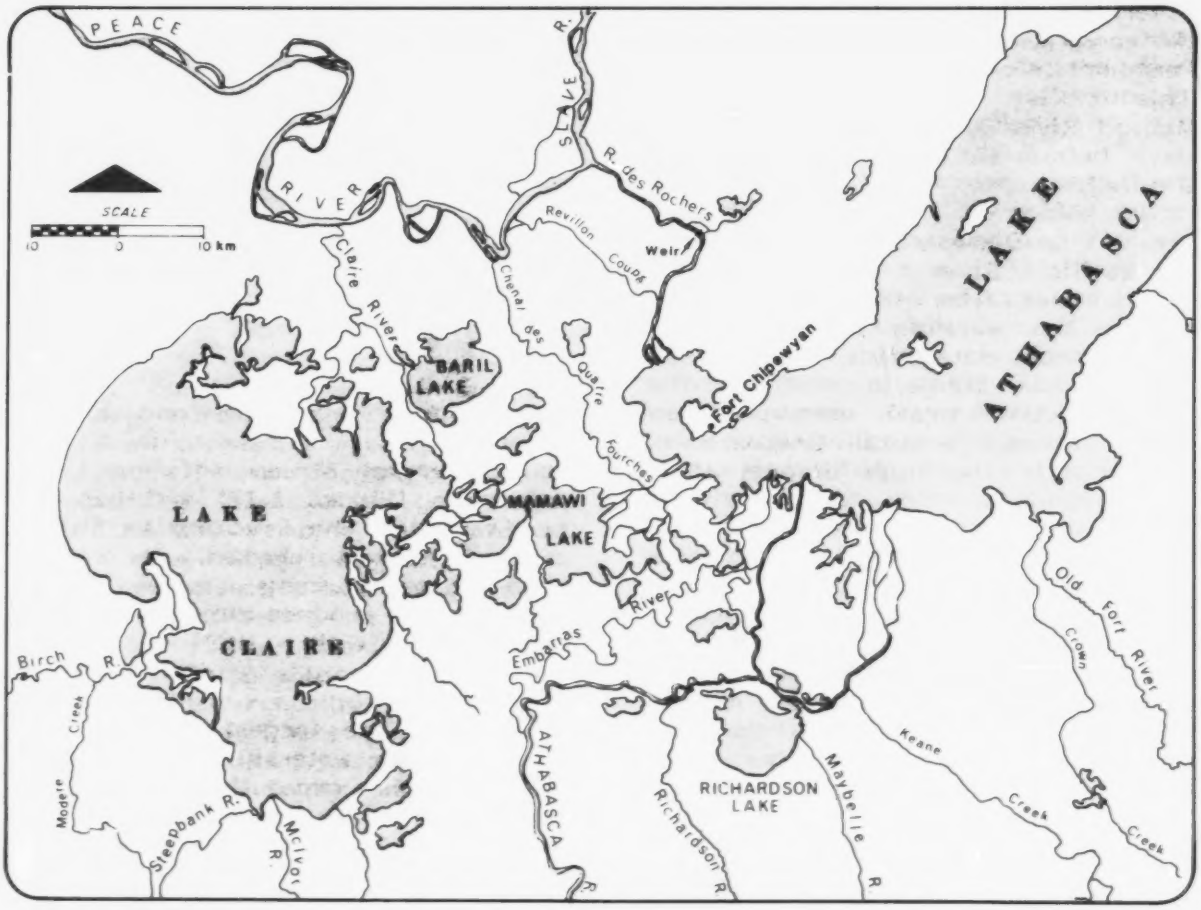


Figure 2.23
Peace-Athabasca Delta

dunes along the Athabasca River, in the lowlands west of the delta, and along the south shore of Lake Athabasca (see subsection under Sensitive Areas).

This colour composite LANDSAT image shows the Peace-Athabasca Delta in the spring of 1974. The largely flooded deltas have become part of Lake Athabasca during the flood. Note the difference in extent of flooding between this scene and that shown in the next LANDSAT image of May 1976 (Figure 2.25).

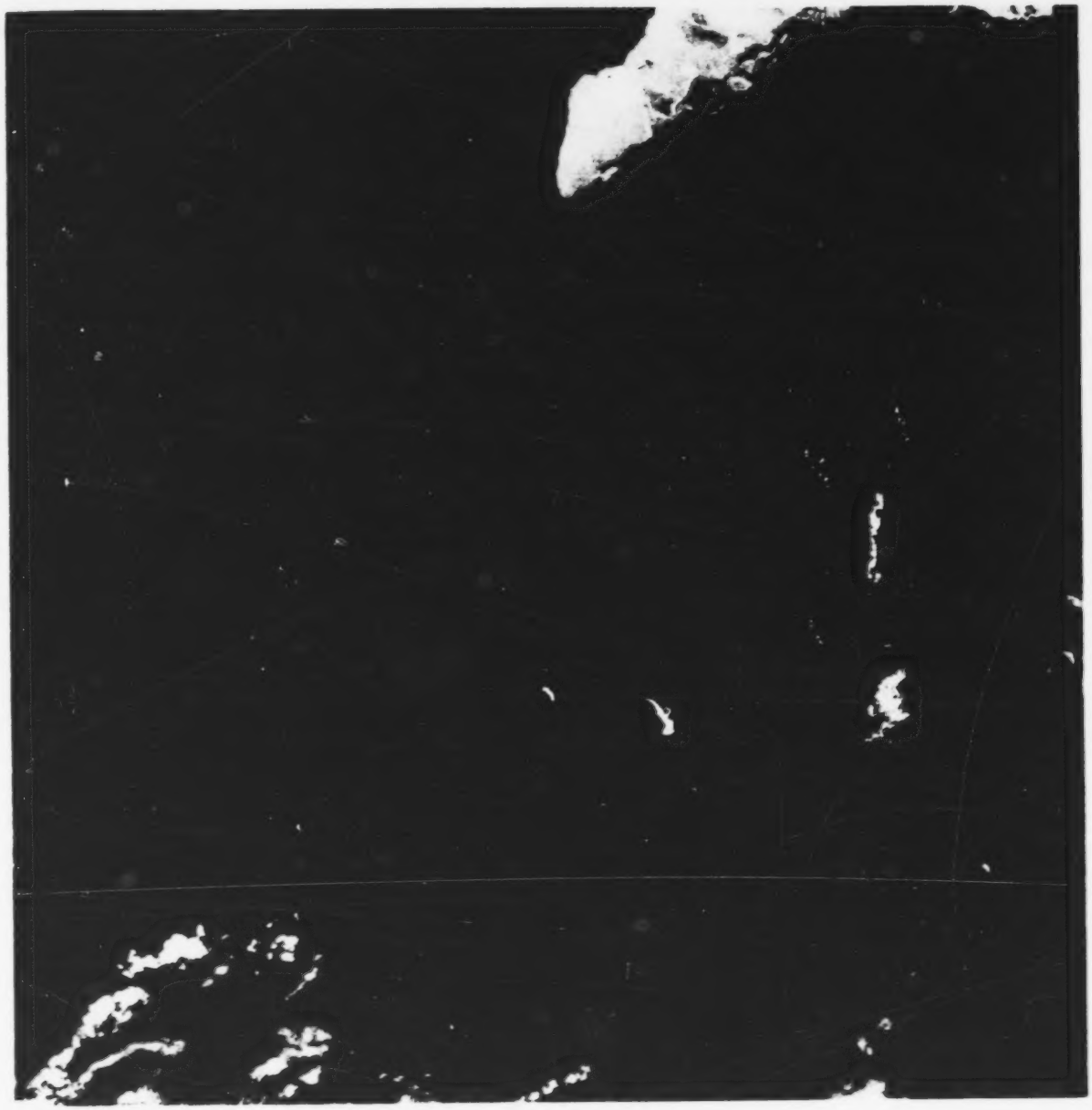


Figure 2.24
Peace-Athabasca Delta
May 22, 1974

The lake was once part of the great fur trade and exploration route to the north. The Hudson's Bay Company built the first trading post at the present site of Fort Chipewyan around 1800, making this the oldest northern settlement in Alberta.

Peace-Athabasca Delta The delta began to form in a depression left at the end of the last ice age, approximately ten thousand years ago. The depression will eventually be filled with sediment and the river will then flow through the mature delta directly to its confluence with the Peace River. The delta is positioned at the very edge of the Precambrian Shield (Figure 2.16).

The Peace and Athabasca Rivers each formed their own delta once, but these have now merged. The Peace River portion is now mature so that the river bypasses the delta except during floods, and no longer extends it. The Athabasca portion is still being enlarged, at the rate of one kilometre over a 20 km front during a period of 24 years. Some of the sediments from the Athabasca River settle out beyond the delta and are filling in the southwestern end of Lake Athabasca (Figures 2.24 and 2.26). As a result the lake at that end is shallow and freezes to the bottom for approximately five kilometres into the lake from the south shore, except for small channels carrying Athabasca River waters.

Historically, the Peace River determined the water levels of Lake Athabasca and the delta, which fluctuated 2 to 3.7 m from year to year. The Peace River would overflow into the delta and lake during high flows, block the normal outflow of the lake, and flood the delta. Ice jams increased the flooding. After construction of the W.A.C. Bennett Dam about 1100 km upstream of the delta, filling of Williston Reservoir reduced peak flows during the period 1968-71 and threatened to substantially reduce delta flooding in subsequent years, as well as lower the level of Lake Athabasca. The filling coincided with a period of lower than normal flow years, which together affected the vegetation, fish, and wildlife adversely.

In order to improve these conditions, the Governments of Canada, Alberta, and Saskatchewan studied the problem and constructed a submerged weir on the Riviere des Rochers at Little Rapids and another on the Revillon Coupe. These structures have restored water levels on Lake Athabasca and the delta close to their levels before the construction of the W.A.C. Bennett Dam. The delta continues to be monitored to determine if any further action is necessary.

The reasons for the concern are that residents of Fort Chipewyan depend heavily on the biological resources of the delta for food and cash income, and that the Peace-Athabasca Delta is of international importance. The delta is a critical staging area for a significant portion of the continental waterfowl population. Hundreds of thousands of waterfowl funnel through the Peace-Athabasca Delta each year, primarily from the Central and Mississippi Flyways (Figure 2.27). The delta is probably the most important northern delta on the continent for waterfowl nesting.

Wood Buffalo National Park, located partly in the delta area, was for many years the world's largest national park and supports the largest free roaming population of bison in the world. This population depends to a large extent on the grasslands of the delta (Figure 2.28).

Current studies by Alberta are addressing the impact on the delta

Note the marked difference between this 1976 spring flood and that of 1974, shown in the preceding image.

Figure 2.25
Peace-Athasbasca Delta
May 29, 1976

This LANDSAT image shows that by late summer 1976 the water surface has receded and lakes within the delta are well defined. In this particular year, because of the low level of spring flooding shown above, the change from spring to summer is hardly noticeable.

Figure 2.26
Peace-Athabasca Delta
August 9, 1976

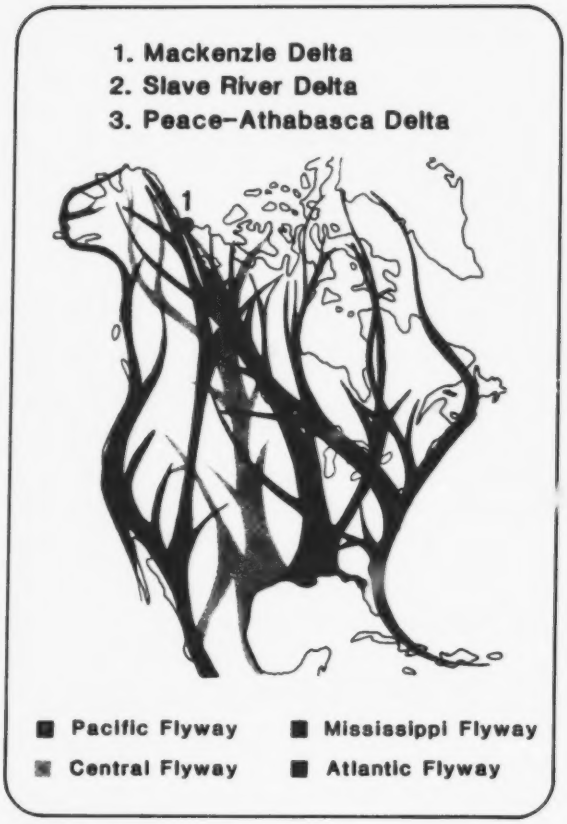


Figure 2.27
North American Flyways

of a potential Slave River hydroelectric power development near Fort Smith, N.W.T.

Sensitive Areas

Athabasca Sand Dunes — This area constitutes the largest area of open sand in the world at this northern latitude. The sand dunes area is considered sensitive because of the uniqueness of the plants, including ten varieties that are endemic to the area, and the instability of the active sand dunes. This instability is due to an uneasy equilibrium between the combined erosive actions of wind and flowing water on the one hand, and the stabilizing actions of groundwater and vegetation on the other hand.

A 1200 km^2 area of the Athabasca Sand Dunes in Saskatchewan was the subject of field investigations under this study program. The results are discussed in Appendix B and described in detail in Supplement 7 to this report.

Clearwater River — The Clearwater River originates in northwestern Saskatchewan and flows 370 km west to join the Athabasca River at Fort McMurray, Alberta. The river was a major travel route during the height of the fur trade. The 21 km Methy Portage connects the Clearwater River with the Churchill River system. The most significant feature of this river is that it has remained almost unchanged since the days of explorers such as Frobisher, Pond, Thompson, and Mackenzie. Proposals have been made to designate the Clearwater River as a wild, historic, and scenic waterway.

The Clearwater system provides high quality fish habitat and an excellent sport fishery for walleye, northern pike, and arctic grayling.

Fond du Lac River and Elizabeth Falls — The Fond du Lac River and Elizabeth Falls located on the river between Black Lake and Middle Lake were examined as sensitive areas because they support a superb fishery for arctic grayling, are part of an historic waterway, and offer spectacular scenery.

West End of Lesser Slave Lake — The west end of Lesser Slave Lake is extremely important to wildlife productivity and depends on the natural water regimes and lake levels. It is a major staging area for waterfowl moving along the Mississippi and Central Flyways and provides excellent habitat for muskrat, mink, and beaver along much of the shoreline. The area is important to a variety of fish for spawning and rearing.

Figure 2.28
Bison
Peace River

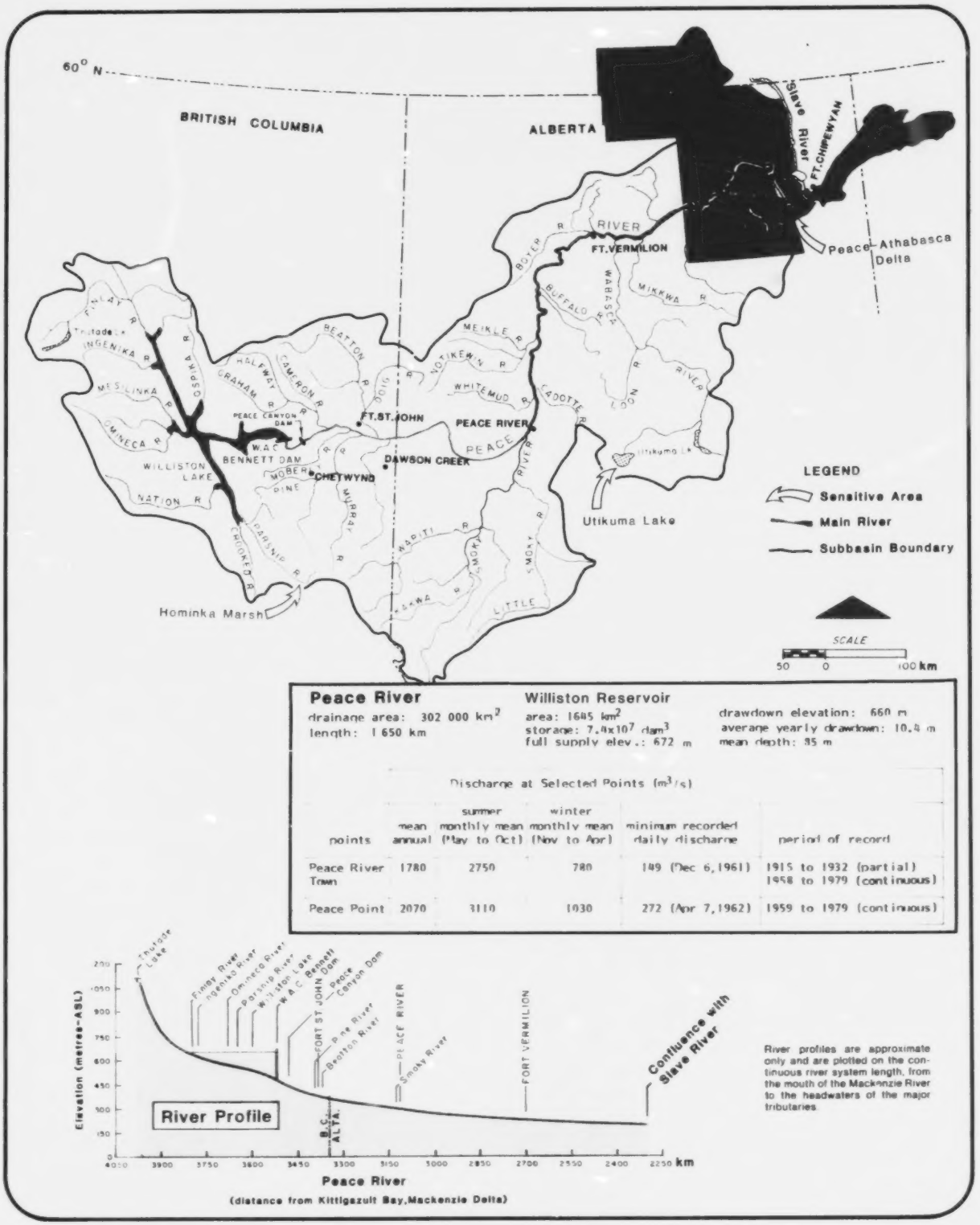

60° N
BRITISH COLUMBIA
ALBERTA
Slave River
FT.CHIPEWYAN
Peace-Athabasca Delta
FT.VERMILION
PEACE RIVER
Hominka Marsh
Utikuma Lake
LEGEND
Sensitive Area
Main River
Subbasin Boundary
SCALE
50 0 100 km
Peace River
drainage area: 302 000 km²
length: 1 650 km
Williston Reservoir
area: 1645 km²
storage: 7.4x10⁷ dam³
full supply elev.: 672 m
drawdown elevation: 660 m
average yearly drawdown: 10.8 m
mean depth: 45 m
Discharge at Selected Points (m³/s)
points | mean annual | summer monthly mean (May to Oct) | winter monthly mean (Nov to Apr) | minimum recorded daily discharge | period of record
Peace River Town | 1780 | 2750 | 780 | 149 (Dec 6,1961) | 1915 to 1932 (partial) 1958 to 1979 (continuous)
Peace Point | 2070 | 3110 | 1030 | 272 (Apr 7,1962) | 1959 to 1979 (continuous)
River Profile
Elevation (metres-ASL)
Peace River
(distance from Kittigazuit Bay,Mackenzie Delta)
Confluence with Slave River
River profiles are approximate only and are plotted on the continuous river system length, from the mouth of the Mackenzie River to the headwaters of the major tributaries.

Figure 2.29

Peace River Subbasin

2. Peace River Subbasin

The Peace River has its source in the Omineca Mountains and generally flows in a southeasterly and then northeasterly direction before terminating at the Peace-Athabasca Delta (Figure 2.29). It is the larger of the two southern tails of the Mackenzie River system in annual flow (Figure 2.12) and is the only major tributary that no longer has a natural flow regime. The river is regulated by two dams in the upper watershed in British Columbia -- the W.A.C. Bennett Dam, which forms Williston Lake, and the Peace Canyon Dam downstream.

Peace River The Peace River begins at the junction of the Finlay and Parsnip Rivers in the Rocky Mountain Trench, and flows directly into Williston Lake. From there the Peace flows through rapids and gorges, and continues eastward through the Rocky Mountains. It then assumes a more moderate slope and winds northward through the Interior Plain until it is joined by the Smoky River just above the Town of Peace River.

The Peace flows about 370 km north to Fort Vermilion, turns northeast, and after 290 km joins the three outflow channels of the Peace-Athabasca Delta to form the Slave River.

Peace River Spring Breakup The breakup on the Peace River has been altered considerably by the construction and operation of the Bennett Dam. The effects of this dam are most noticeable closest to the dam and become attenuated farther downstream.

The B.C. Hydro and Power Authority has found that the water temperatures of the dam outflows vary from 4°C in November to 1°C in February or March. This release of relatively warm water, coupled with the loss of ice-producing channel upstream of the dam, causes a mechanical destruction of the ice cover at the rate of 5 to 15 km a day.

Before construction of the Bennett Dam, the Smoky River in most years broke up the Peace River below the Town of Peace River, leaving the Peace River upstream ice bound. The main effect of the dam on this process is the earlier breakup of the Peace River on its own. For example in 1977, the Peace River became ice free on March 12 and the Smoky River only on April 16.

The Smoky River causes flooding at the Town of Peace River when high runoff from the Smoky is blocked by ice below the town, as happened in 1974. In 1979 a jam formed at the mouth of the Smoky River which sent a flood wave down the Peace River when it broke, nearly overtopping the dykes. Since the Bennett Dam has been in operation, the breakup levels have exceeded the normal average of 314 m three times (by three metres). This compares with a 100-year return period flood level of 319 m.

Breakup between the Towns of Peace River and Fort Vermilion generally occurs by a succession of ice jams. Serious flooding occurred during high runoff years like 1963, 1973, and 1979, when local inflow from the melt in the Peace River Subbasin was sufficient to prolong the effects of the flood peaks from the Smoky River. Ice jams can occur on the remainder of the Peace River. For example, in 1976 Vermilion Falls was completely submerged by an ice jam.

Alberta Environment and the British Columbia Hydro and Power Authority have cooperated informally for several years to minimize flooding in the spring. A more complete discussion of the Peace River spring breakup is found in Supplement 3.

Figure 2.30
W. A. C. Bennett Dam
Williston Lake

Sensitive Areas

Hominka Marsh Hominka Marsh is a shallow backwater area of the Hominka River. The marsh is an important area because it is one of the few remaining good quality migratory waterfowl habitats in the northern half of the Rocky Mountain Trench. Habitat that existed along the lower Parsnip and Finlay Rivers was destroyed by the filling of Williston Lake. The area is an important winter range and calving area for moose. Beaver and muskrat are plentiful and other important fur-bearers are found in the area. The marsh area is important to staging and nesting waterfowl and is used by local people for subsistence hunting and trapping. The productivity of the area depends heavily on the natural flow regime of the Hominka River.

Utikuma Lake Utikuma Lake is part of an extensive wetland centred in the Utikuma Upland physiographic region. The extensive

wetlands and shallow offshore areas are used extensively by moulting, nesting, and migrating waterfowl. A colony of up to 500 pelicans is on a small island in the lake. The importance of Utikuma Lake to waterfowl is most evident during migrations when concentrations of ducks in the hundreds of thousands are a common sight.

Waterfowl habitat is maintained by naturally fluctuating water levels in response to flood and drought. Utikuma Lake is the most productive lake for whitefish in Alberta; northern pike are numerous and cisco occur in smaller numbers. The lake contributes to the local economy through both a domestic and a small commercial fishery.

Two oil and gas fields, Utikuma and Nipsi, are in production north of Utikuma Lake. The effect of the two operations has increased air traffic in the area, although no flight restrictions on helicopter and airborne traffic such as those for the Hay-Zama Lakes region of Alberta have been imposed.

Peace-Athabasca Delta The Peace portion of the delta and the effect of Peace River regulation on the delta are discussed as part of the Lake Athabasca Subbasin.

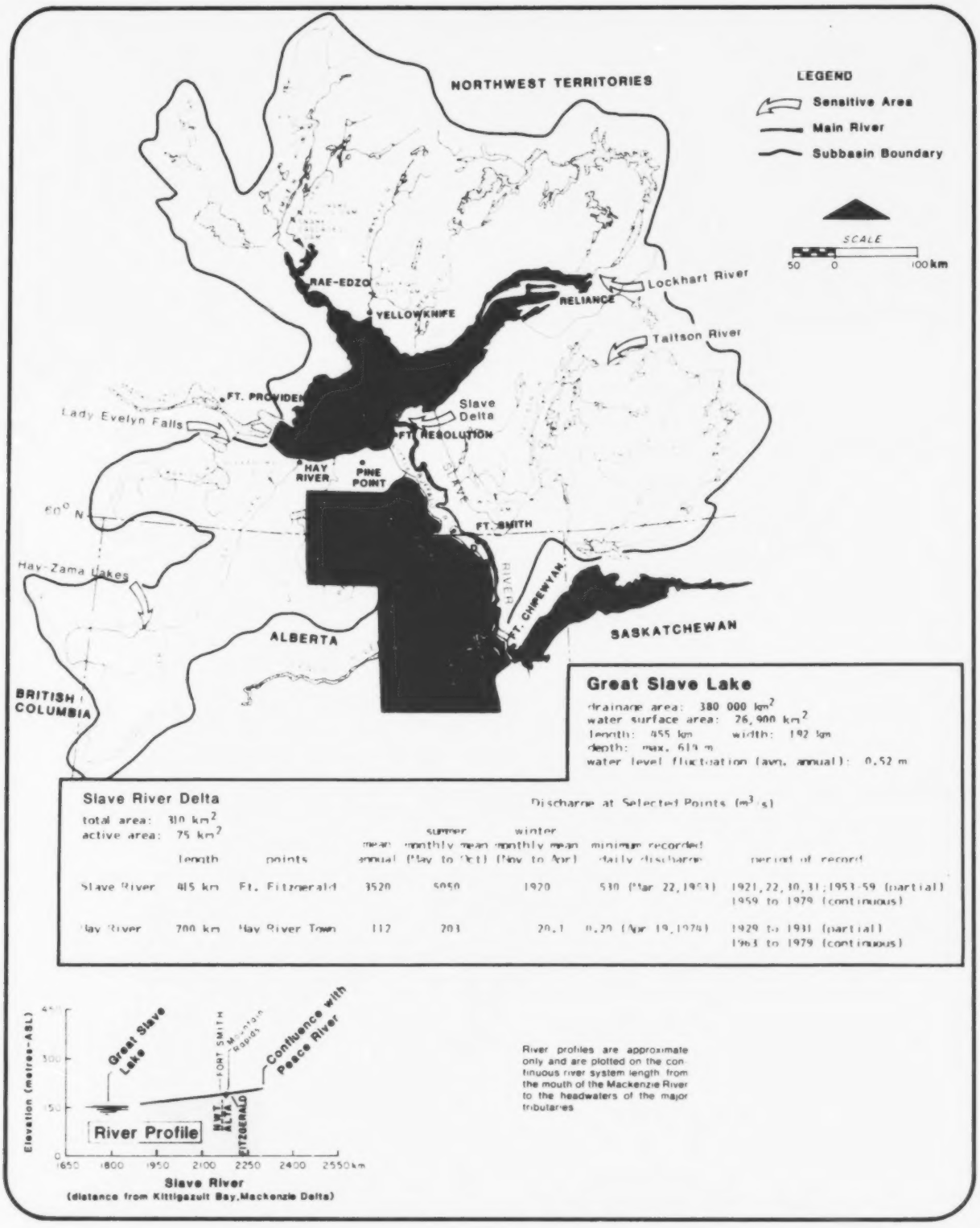


Figure 2.31

Great Slave Lake Subbasin

3. Great Slave Lake Subbasin

Great Slave Lake is centrally located in the Mackenzie River Basin, and plays a very important role in the Mackenzie system. Its main inflow, the Slave River, combines the contribution of the two southern subbasins (Figure 2.20) and enters the lake by way of the Slave Delta. The lake's only outflow is the Mackenzie River itself (Figure 2.31). The lake stabilizes the flow, water temperature, and water levels of the entire upper Mackenzie River and supplies it with sediment-free water.

Slave River The Slave River combines the outflow of the Lake Athabasca and Peace River Subbasins (Figure 2.31). The river flows 415 km in a northwesterly direction and can be divided into three distinct reaches:

a. The extremely flat upper reach, between the confluence and Fitzgerald, falls only 4.6 m in 3 km.

b. The middle reach, between Fitzgerald and Fort Smith, falls about 35 m in 24 km as it crosses the Shield. Four sets of rapids occur here: Cassette, Pelican, and Mountain Rapids and Rapids of the Drowned, more commonly called the Fort Smith Rapids (Figure 2.32).

c. The lower reach, between Fort Smith and Great Slave Lake, also has a very flat slope, falling about 10.7 m in 250 km. This last reach is actually a former estuary of Great Slave Lake, now filled in by river sediment which is actively building up the Slave River Delta.

Figure 2.32
Mountain Rapids

Throughout most of its length the east bank of the Slave River is formed by rocks of the Shield, while its west bank is formed by Interior Plain sediments, although there are numerous outcrops of Shield rocks on the west bank. The rapids in the middle reach are caused by spurs of the Shield crossing the river in an east-west direction. The peninsula of Mountain Rapids is the most prominent such outcrop on the west bank.

Slave River Delta The Slave River Delta is the second of the three major deltas in the Mackenzie system, and is typically bow shaped. It is situated on four continental flyways and therefore is of international significance for migratory birds, although less so than the nearby Peace-Athabasca Delta or the Mackenzie Delta. Like all delta ecosystems it depends on the continued deposition of fresh sediment and periodic flooding for its biologic productivity.

The Slave River Delta was the subject of field investigations under this study program. The results are discussed in Appendix A and described in detail in Supplement 6 to this report.

Hay River The Hay River rises near Fort Nelson and then flows about 700 km northeast until it empties into Great Slave Lake at Hay River. The runoff peaks sharply in the spring, with daily discharges between 374 and 1174 m^3/s (1970-74). This contrasts greatly with the usually less than 3 m^3/s daily flow during the winter months. Major frontal weather systems with intense precipitation can cause summer peaks which briefly exceed spring peak flows.

In spite of the perennial threat of flooding, most industries of the Town of Hay River are located on Vale Island, the largest of the delta islands formed where the Hay River splits into the East and West Channels. A modern residential community was established on the mainland in the mid-1960's to avoid future flooding and to take advantage of better soil conditions for building and public utility installations.

Flooding results from a combination of high flows and ice jams at or near the mouth of the river, particularly the East Channel. The primary cause of these jams is the accumulation of river ice on the still frozen surface of Great Slave Lake, since the river breaks up before the lake.

Great Slave Lake Great Slave Lake is the second largest of the three major lakes in the Mackenzie system and is the fourth largest lake in Canada. The lake spans two physiographic zones (Figure 2.16). The east arm in the Shield is up to 614 m deep and its shoreline is rugged, with high cliffs and numerous rocky islands. It is fed by a relatively uniform flow of clear cold water from such tributaries as the Taltson River. Water transparency in this arm can be up to 15 m. The eastern half of the North Arm is also in the Shield (Figure 2.33). The capital of the Northwest Territories, Yellowknife, is located on Yellowknife Bay, an extension of the North Arm.

The western part of the lake, including the west arm where the Mackenzie River originates, is located in the Interior Plain. It is characterized by a regular shoreline and water up to 162 m deep. A south arm, which once connected this lake to Lake Athabasca during the last ice retreat, is now filled with Slave River sediment. The Slave River supplies 87% of the total annual discharge to Great Slave Lake, and along with the Hay River continues to supply warm and sediment-laden water to the lake. The transparency of 3 to 5 m in the west

1 Yellowknife
2 N.W.T. Highway No. 3 to Fort Providence and Hay River
3 Rae-Edzo
4 Precambrian Shield
5 Sedimentary rocks of the Interior Plain
6 Suspended sediments
7 Ice flow markings (SW/NE direction) and salt deposits around rim of shallow lakes

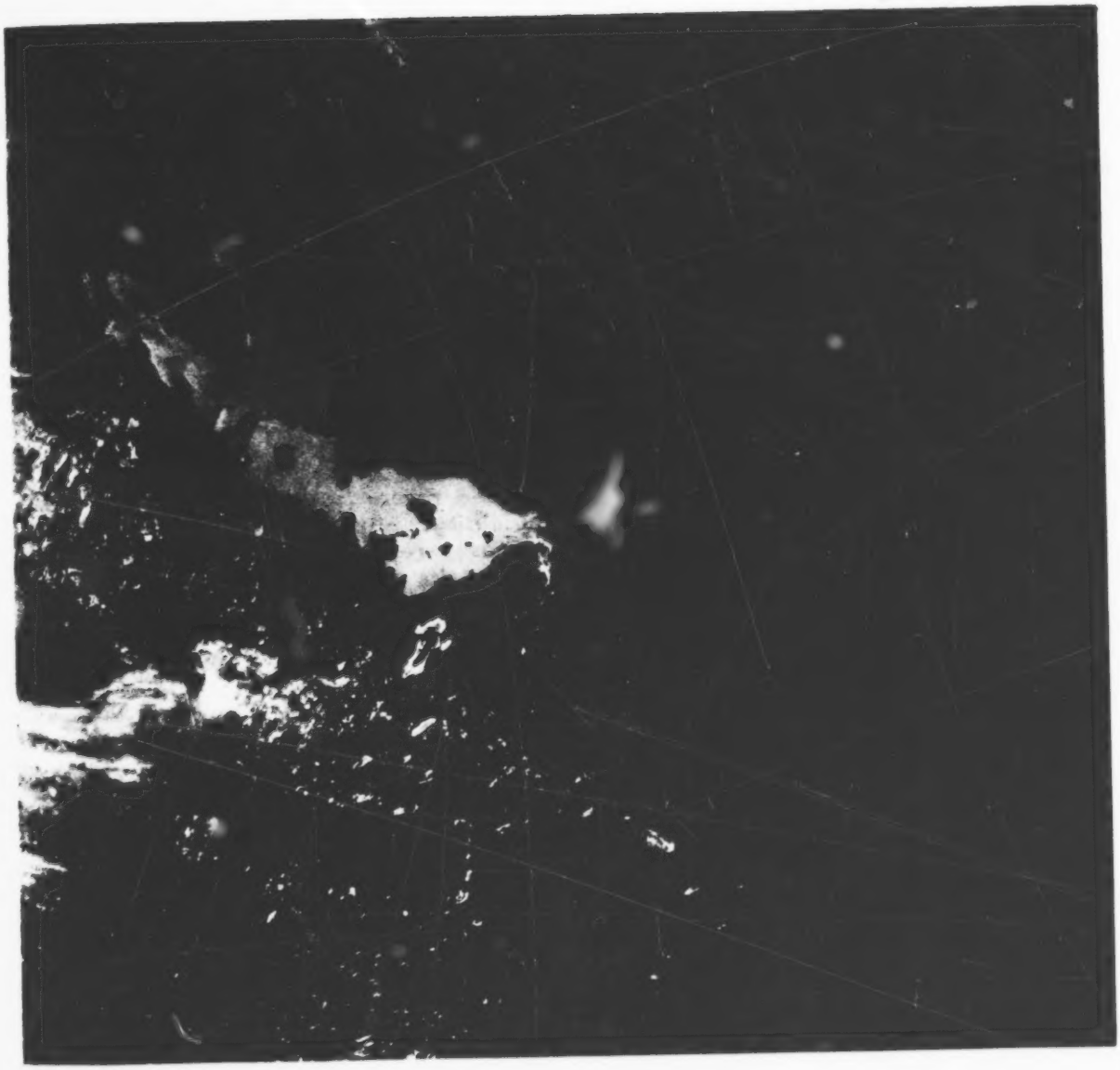


Figure 2.33
Great Slave Lake
North Arm

basin is therefore much lower than in the east arm, and can be less than 0.2 m in the immediate vicinity of the Slave River Delta. Flushing time, however, has been calculated at 7 years, compared with 12 years for the whole lake.

The huge size of the lake ensures relatively stable lake levels and water temperatures, with the result that the upper Mackenzie River has a relatively uniform flow and somewhat delayed freezeup and breakup. The lake stores the summer's heat and releases it to the river during fall, thereby delaying freezeup. Conversely, in the spring the opposite effect is felt: the presence of lake ice maintains a cool flow of water into the river and delays breakup. The outflow from the lake and the freezeup and breakup are also affected by wind.

Sensitive Areas

Taltson River The Taltson River is 700 km long and flows from the east and south to Great Slave Lake. Over much of its upper course the river drains a chain of lakes. In contrast, the last 250 km is free of lakes. The river is characterized by sediment-free cold water which provides excellent habitat for a variety of fish species.

A large number of raptor species occur in the area, including bald eagles and osprey. During spring and fall migrations, waterfowl are present throughout the watershed. Barren-ground caribou and moose are also common in the area.

Investigations so far have concentrated on the aquatic environment upstream of the hydroelectric power installation above Elsie Falls. A significant amount of detailed biophysical information is available for the Taltson River system, but the effects of the existing hydro development have not been fully assessed.

Lockhart River The Lockhart River flows 480 km in a large inverted arc across the Shield into the northeastern end of Great Slave Lake. The Lockhart River is particularly interesting along its final 32 km between Artillery Lake and Great Slave Lake. This area is a proposed International Biological Program (IBP) site and has been considered for a possible national park.

In this lower reach the Lockhart River falls more than 180 m as it tumbles over a variety of rapids, backs into quiet pools, and roars over spectacular waterfalls. The area provides habitat for bird species such as bald and golden eagles, gyrfalcons, peregrine falcons, and merlins. The East Arm of Great Slave Lake is identified as particularly important for rare and endangered raptor species which nest in the vicinity. Barren-ground caribou and moose are the main mammals present, and lake trout are the most abundant and widely sought after sport and domestic fish in the area. Archaeological artifacts are common and several sites have been found.

Lady Evelyn Falls Lady Evelyn Falls is located on the lower reach of the Kakisa River between Kakisa Lake and the Mackenzie River (Figure 2.34). This area has scenic value and supports a small but popular sport fishery for arctic grayling below the falls. The Kakisa River itself has a fall spawning run of lake whitefish and contains walleye and northern pike, among others. The outlet of Kakisa Lake is open all year and is therefore available to early migrating waterfowl. Some assessment has been made of the possible effects

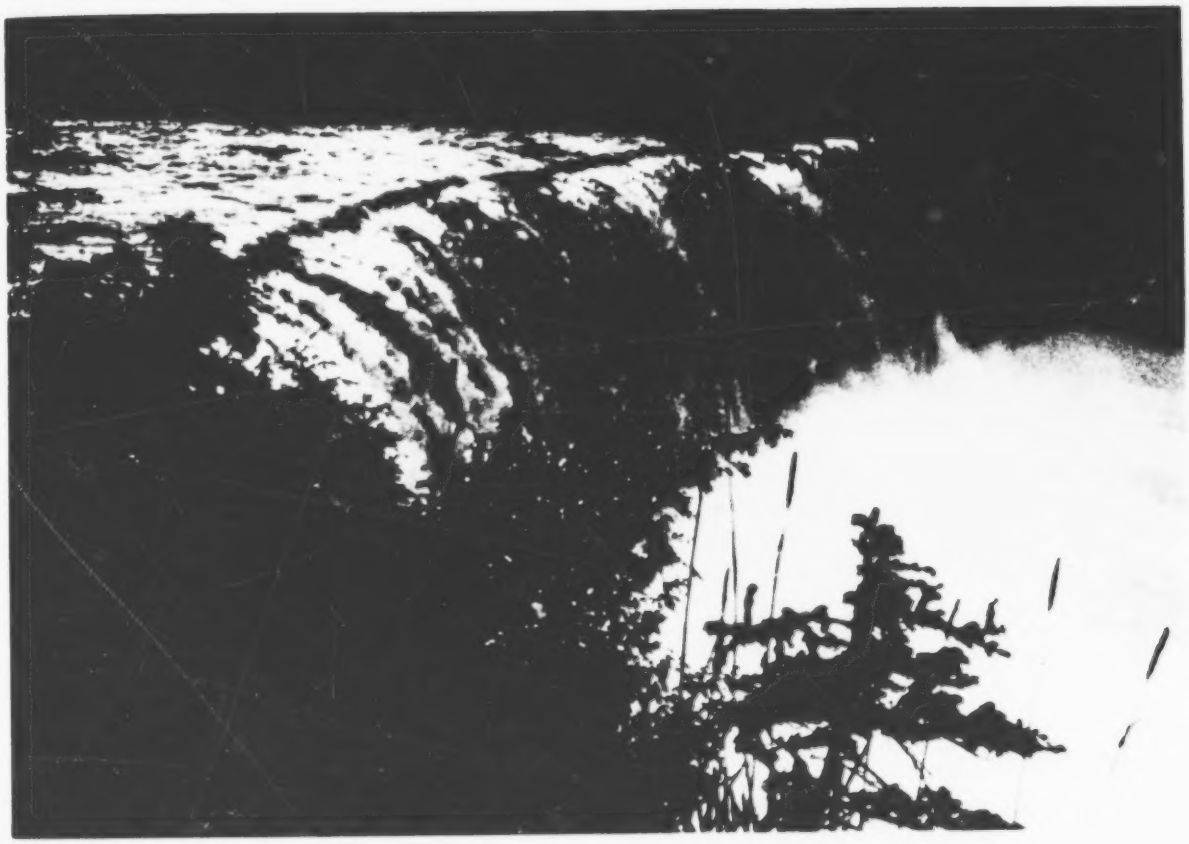


Figure 2.34
Lady Evelyn Falls

of a proposed hydroelectric power development at the falls.

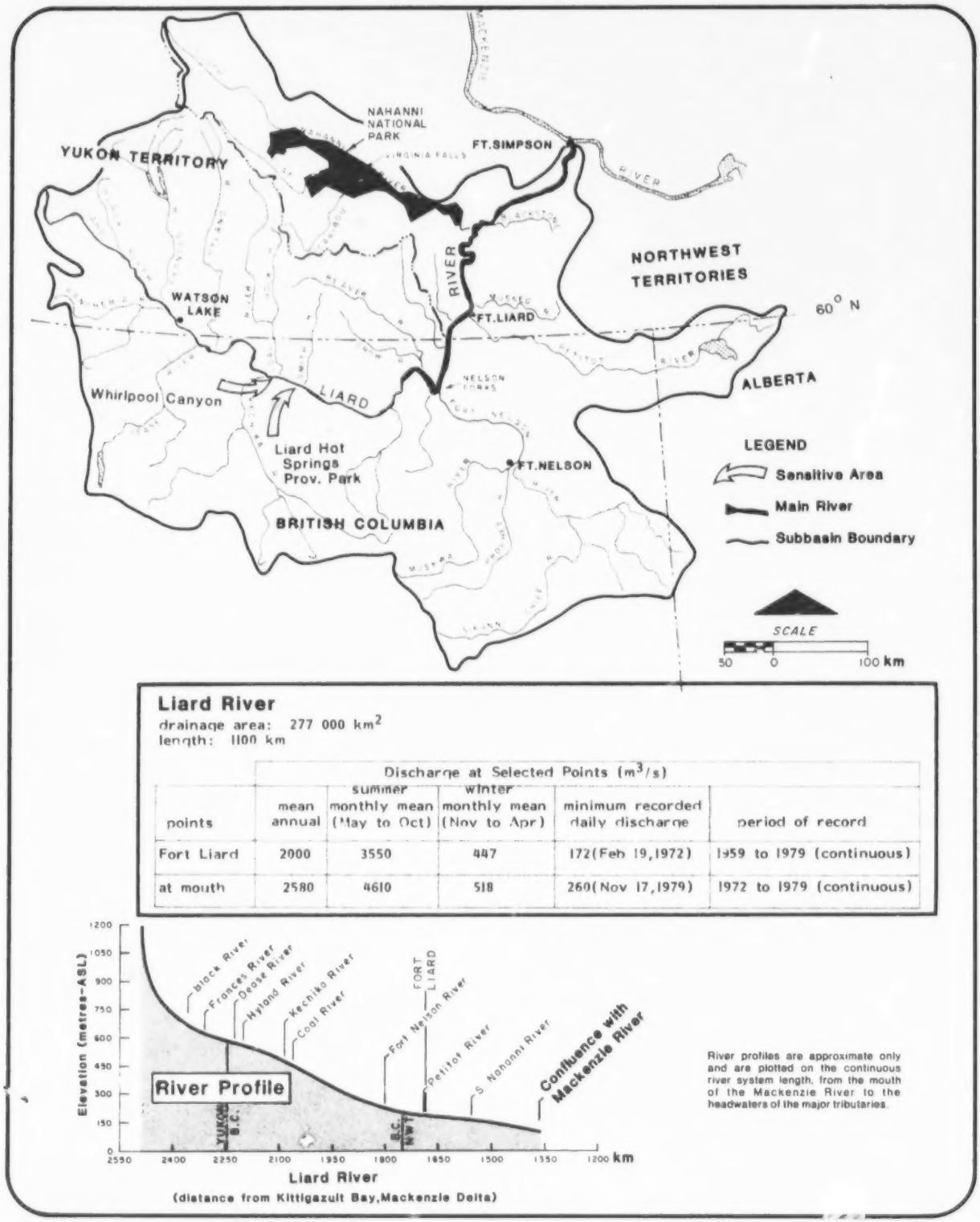
Hay Zama Lakes The Hay-Zama Lakes wetland complex is a 410 km^2 floodplain in the upper Hay River. In some years the area experiences large and repeated flow variations and therefore fluctuations in lake levels. The flood and recession character of the hydrologic regime is analagous to that of a delta complex.

The complex is one of the largest native grassland areas in northern Alberta. It provides a large tract of waterfowl habitat with very good production capability. Because the region has little other suitable habitat for nesting or migrating waterfowl, the Hay-Zama Lakes are an extremely important migration stop for large numbers of ducks and geese using both the Pacific and Central Flyways.

Three oil and gas fields encroach on the complex. Extensive exploration and development have left a system of rough roads and airstrips. Restrictions have been placed on helicopter and airboat traffic during staging and nesting periods to ensure protection of the waterfowl at this critical time.

Use of the area by migratory birds has been well documented. The area appears to be suitable for fur bearing animals although inventories have not been conducted. Also, potential changes in the hydrologic regime and associated changes in the vegetation have not been studied.

Figure 2.35
South Nahanni River
Nahanni National Park



Liard River

drainage area: 277 000 km^2
length: 1100 km

	Discharge at Selected Points (m^3/s)				
points	mean annual	summer monthly mean (May to Oct)	winter monthly mean (Nov to Apr)	minimum recorded daily discharge	period of record
Fort Liard	2000	3550	447	172(Feb 19,1972)	1959 to 1979 (continuous)
at mouth	2580	4610	518	260(Nov 17,1979)	1972 to 1979 (continuous)

River profiles are approximate only and are plotted on the continuous river system length, from the mouth of the Mackenzie River to the headwaters of the major tributaries.

Figure 2.36

Liard River Subbasin

4. Liard River Subbasin

The Liard River Subbasin extends across portions of British Columbia and Alberta, and the Yukon and Northwest Territories (Figure 2.36). The Liard River is one of the major tributaries of the Mackenzie River, and is instrumental in the spring breakup of the Mackenzie River ice. It is also a major contributor of suspended sediment, which is so important to the alluvial ecosystems downstream. Nahanni National Park and Virginia Falls on the South Nahanni River are located in this subbasin.

Liard River The Liard River is the eleventh longest river in Canada and has the seventh largest mean annual discharge. It starts in the Pelly Mountains of the Yukon and flows southeast into British Columbia, until it is joined by the Fort Nelson River. Then it turns north, and meets the Mackenzie River at Fort Simpson.

Most of the Liard River Subbasin is underlain by easily eroded sedimentary rock which accounts for very high sediment loads in its streams. Sediment loads are maintained in the Liard River and its tributaries because there are no lakes to filter out the sediment or to moderate streamflow. The main tributaries drain a variety of physiographic areas resulting in a complex hydrologic regime which is not well understood.

The Liard River exercises the greatest influence of any tributary on the Mackenzie River flow, temperature, sediment load, and breakup. The Liard River is significantly warmer and contains more suspended sediment than the Mackenzie above Fort Simpson. In most years this warm silty spring floodwater lifts up, breaks, and moves out the winter ice cover from the Mackenzie River. The relatively warm Liard River water advances the open-water season ahead of the surrounding area.

The spring breakup on the Liard River was the subject of field investigations under this study program. The results are discussed in Chapter 4 and described in detail in Supplement 3 to this report.

Sensitive Areas

Nahanni National Park The central feature of the park is the South Nahanni River, one of North America's finest wild rivers. It meanders for 320 km through country containing a variety of geologic and biologic features, including many hot springs, areas of wildlife habitat, several unusual floral communities, and a well developed system of canyons, natural caves, and karst topography.

The river descends from the ragged range of the Selwyn Mountains and plunges over the 90 m high Virginia Falls (Figure 2.38). Twenty-three kilometres downstream it reaches a constricted area of treacherous rapids known as Figure Eight or Hell's Gate. Ten kilometres farther downstream, the Flat River joins the South Nahanni and below this confluence lies Third Canyon, which is 19 km long and up to 1000 m deep. The river then continues to Second Canyon, which is another narrow, steep-walled section. Next, the river reaches First Canyon in a remote section of the Mackenzie Mountains, which remained untouched during the last glaciation. Here precipitous cliffs rise 1100 m above the river, with many caves throughout this steep limestone formation. Finally, the river reaches the Splits, an area beginning at the southeast park boundary. The river becomes shallow here and divides into a braided series of channels, 50 km long and up to 3 km wide.

Nahanni National Park offers numerous other attractions. These include the sulphur hotsprings occurring at the mouth of First Canyon, where the waters remain at 32°C the year long and produce an area of luxuriant vegetation growth; Wildmint Hotsprings in the vicinity of the Flat River, where several plant species have significantly extended their range northward; and Rabbitkettle Hotsprings in the northwest portion of the park, which have formed a spectacular terraced, flat-topped deposit, 60 m in diameter and rising 27 m above the Rabbitkettle River(Figure 2.37). The main activities in this park are white-water canoeing, hiking, sightseeing, and wildlife photography.

Thirty-one mammalian species have been recorded in the park, including moose, woodland caribou, Dall's sheep, grizzly bear, and black bear.

Liard Hot Springs

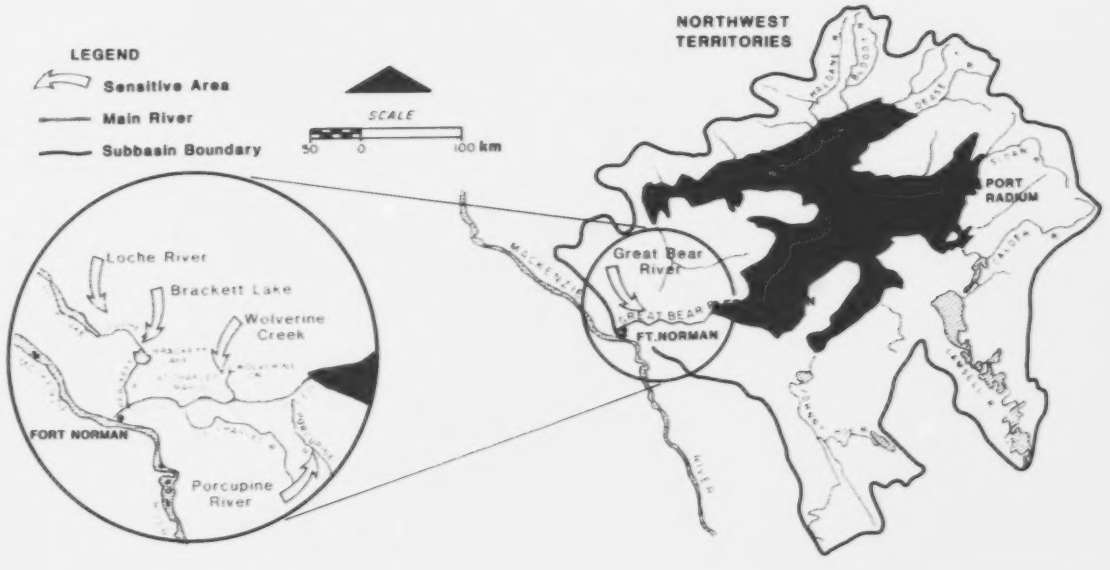
The Liard Hot Springs are two large pools, with associated smaller pools and cascading rivulets. Drainage from the hot springs enters an extensive swamp and muskeg area. The area is a relic of a past era with a much warmer climate. This "tropical valley" environment contains 82 species of plants normally found in more southern latitudes. The area is located near potential hydroelectric sites and will be affected by such development. Liard Hot Springs is currently a British Columbia Provincial Park.

Whirlpool Canyon

Whirlpool Canyon is located 80 km upstream of Liard Hot Springs, near the confluence of the Coal and Liard Rivers. This canyon is both a scenic and canoeing attraction. It features standing waves two metres high, currents running in almost every direction, and powerful whirlpools where the river gushes into a large bay.

Figure 2.37
Rabbitkettle Hotsprings
Nahanni National Park

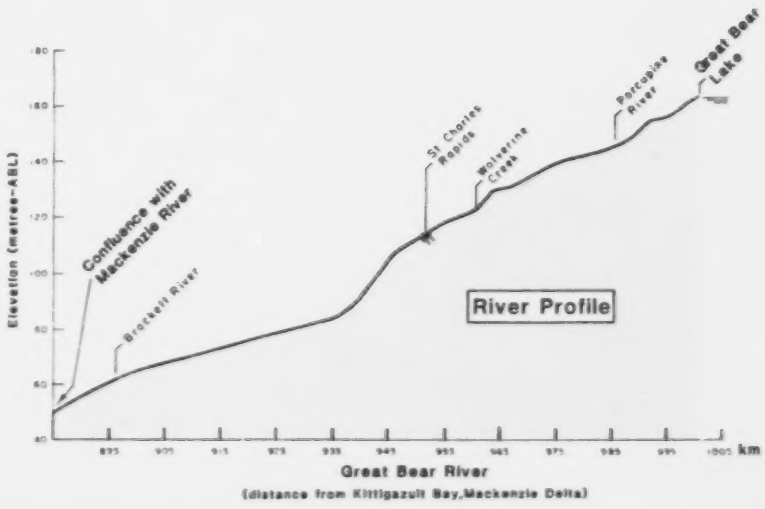
Figure 2.38
Virginia Falls
Nahanni National Park



Great Bear Lake

drainage area: 158 000 km^2
water surface area: 30 800 km^2
length: 336 km width: 169 km
depth: max. 413 m
water level fluctuation (avg. annual): 0.34 m

			Discharge at Selected Points (m^3/s)				
	length	points	mean annual	summer monthly mean (May to Oct)	winter monthly mean (Nov to Apr)	minimum recorded daily discharge	period of record
Great Bear River	118 km	Outlet of Great Bear Lake	516	540	493	132 (Apr 27, 1948)	1938 to 1962 (seasonal) 1963 to 1980 (continuous)



River profiles are approximate only and are plotted on the continuous river system length, from the mouth of the Mackenzie River to the headwaters of the major tributaries.

Figure 2.39
Great Bear River Subbasin

1 Great Bear River
2 St. Charles Rapids where the Great Bear River cuts through the Franklin Mountains
3 Franklin Mountains
4 Confluence of Great Bear and Mackenzie Rivers at Fort Norman
5 Brackett Lake
6 Kelly Lake
7 Norman Range
8 Norman Wells
9 Three Day Lake
10 Great Bear Lake

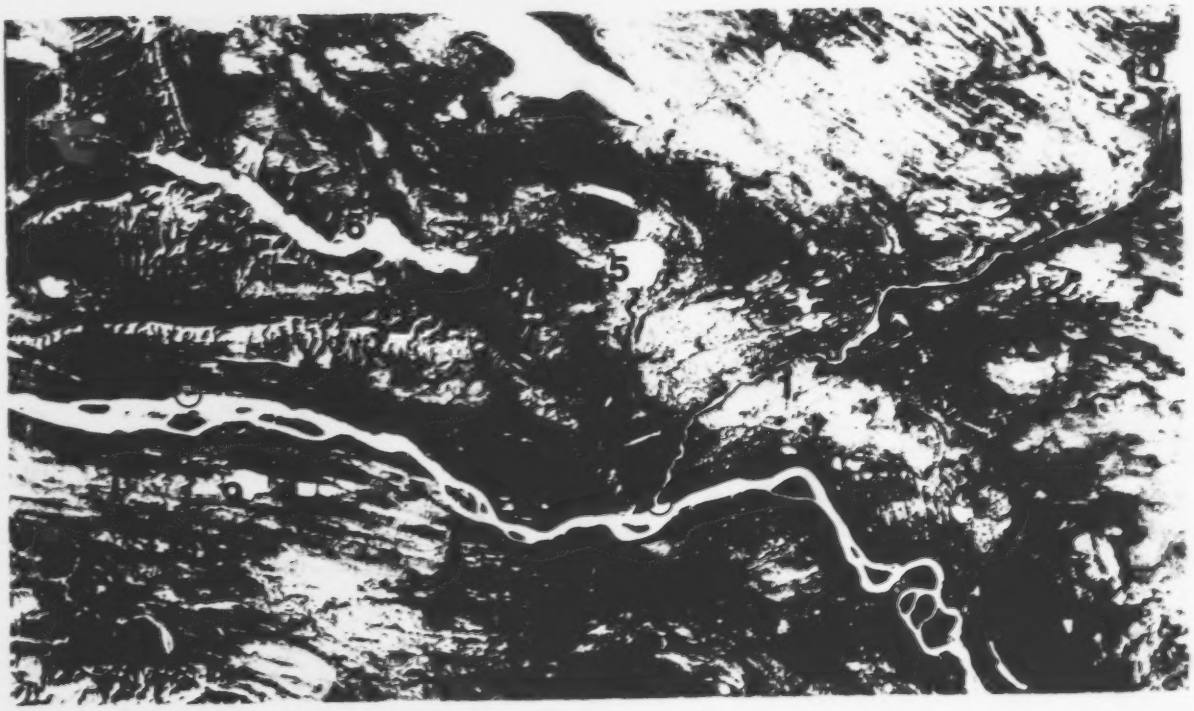


Figure 2.40
Great Bear River

5. Great Bear River Subbasin

This is the smallest of the six subbasins, and about one third of it is occupied by Great Bear Lake. The Great Bear River is the shortest of the major Mackenzie tributaries (Figure 2.39).

Great Bear Lake Great Bear Lake, the largest freshwater lake entirely in Canada, has no major tributaries and is up to 413 m deep. The ice cover may remain into July and the navigational season is only 60 days, the shortest in the Mackenzie Basin. When free of ice, the lake is subject to sudden and violent storms.

Fort Franklin and Port Radium are the only two settlements on Great Bear Lake and receive community supplies by air from Fort Norman. Road access is limited to a winter road joining Fort Norman to Fort Franklin. Two mines are in operation: the Echo Bay Mines and Terra Mine near Port Radium. Several sport fishing lodges are also located on the lake and there is a CN telecommunication relay station at Glacier Bay.

Great Bear River The Great Bear River, which is the only outflow of Great Bear Lake, flows 118 km west to its confluence with the Mackenzie River at Fort Norman (Figure 2.40). The river drops 113 m over this distance and the gradient varies from 0.5 to 1.9 m/km,

Figure 2.41
Great Bear River

creating extremely fast waters. The river is divided into sections by the St. Charles Rapids.

The east section from Great Bear Lake to the portage road above the rapids is about 50 km in length and drops 50 m. The maximum draft for river transportation in this section is about 90 cm and the current velocity is 8 to 18 km/h. The St. Charles Rapids section drops 30 m in 18 km and has a depth of 30 cm. This reach has potential for hydroelectric power development. A 15 km long portage road bypasses the rapids. The western section below the rapids is about 50 km long and drops 30 m to the Mackenzie River. The maximum draft is about 90 cm and the current ranges in velocity from 6 to 13 km/h.

The discharge of the Great Bear River is relatively stable. The river is navigable by barge except at the St. Charles Rapids. Travellers who have come down the Great Bear River in canoes claim that the sudden change in air temperature when they reach the Mackenzie is dramatic. The cooling influence of the Great Bear River can be measured for a long distance downstream in the Mackenzie River. The clear waters of the Great Bear River (Figure 2.41) can also be distinguished for many kilometres after it joins the Mackenzie River. Freezeup occurs between mid-October and late November, while breakup begins in mid-May. Ice jams on the Mackenzie River in spring sometimes back water into the Great Bear River.

The river contains a summer resident population of arctic grayling, but some 25 species of fish have been recorded. Domestic fishing occurs all year and is an important food supplement to residents of Fort Norman and Fort Franklin. This system has excellent sport fishing and recreation potential.

Sensitive Areas

Great Bear River Preliminary investigations for hydroelectric power development on the

Great Bear River have been made for small dams as well as large-scale projects which could require diversion of the Coppermine River into Great Bear Lake. Some preliminary analyses of impacts to be expected from dam construction on the Great Bear River have been completed; however, the available information regarding biotic resources is too general. The main environmental concern identified is the potential impact on arctic grayling.

The main spawning area for arctic grayling in this watershed is Wolverine Creek. The size of the population is unknown although the run exceeds 10 000 fish. The Porcupine River also supports spawning arctic grayling and is thought to be a spawning area for northern pike and ninespine stickleback.

Brackett and Loche Rivers

The Loche River starts at Kelly Lake and flows south to Brackett Lake, which drains via the Brackett River into Great Bear River. In spring the Brackett Lake wetlands support the highest densities of nesting ducks recorded in the Mackenzie River Basin north of 60°. It is a critical moulting area as well as an important late summer and fall staging area for arctic nesting waterfowl. Sections of the Brackett and Loche Rivers that remain open during winter are important for the maintenance of local beaver and otter populations. Brackett Lake is the largest of the few wetlands in the Mackenzie River Valley capable of supporting a relatively stable population of these mammals. The Brackett River is a spawning and nursery area for several fish species. The Brackett Lake area and wetland complex is a proposed International Biological Program (IBP) site.

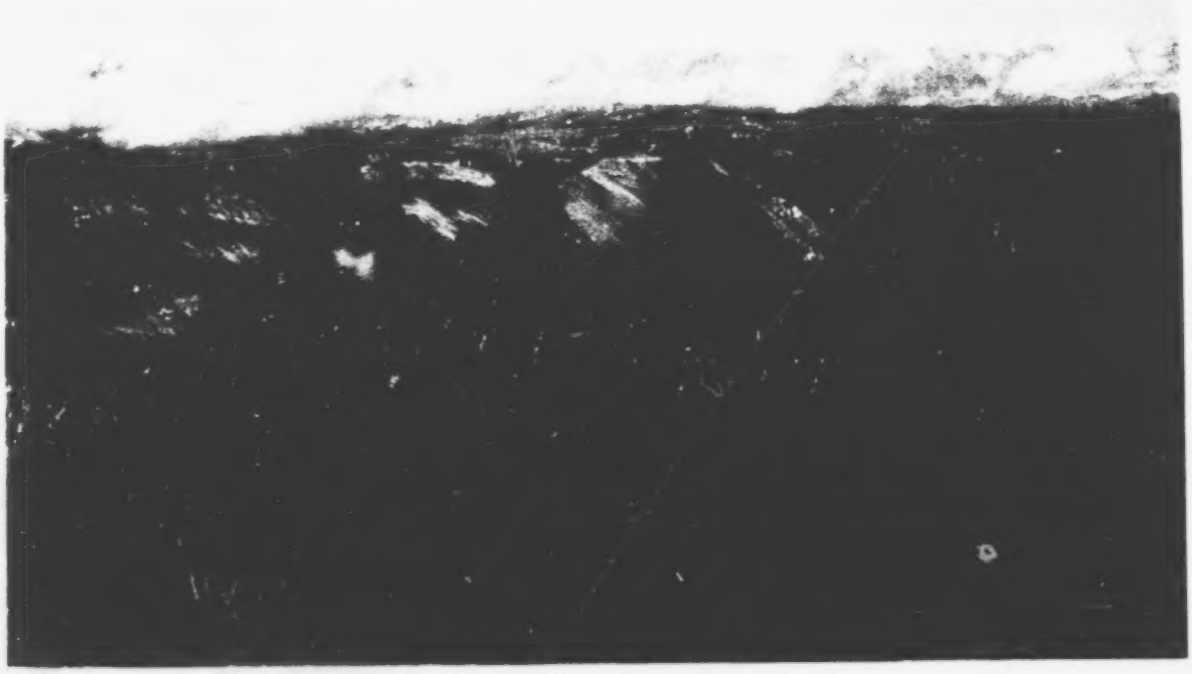


Figure 2.42
Mackenzie Mountains

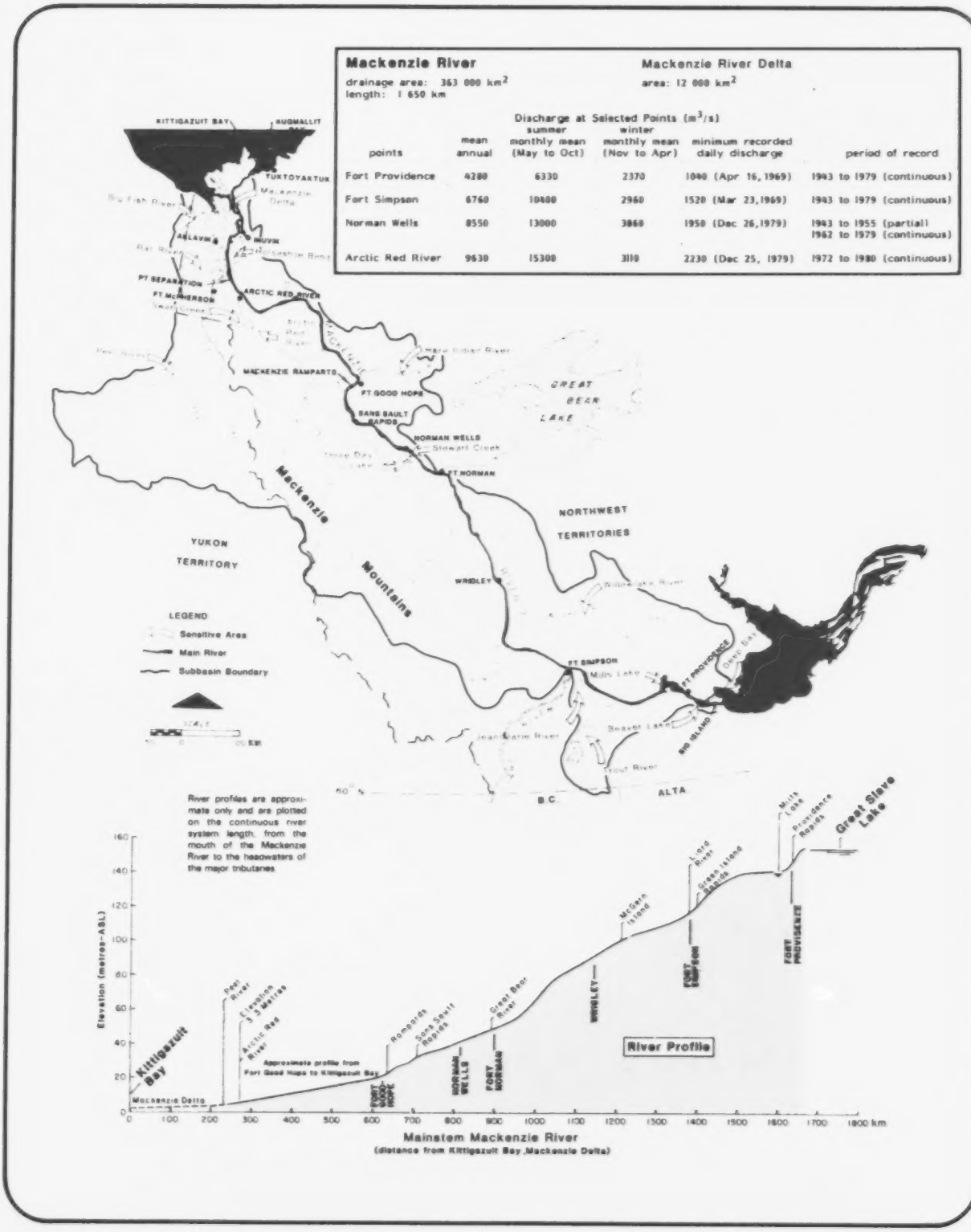

Mackenzie River
drainage area: 363 000 km²
length: 1 650 km
Mackenzie River Delta
area: 12 000 km²
Discharge at Selected Points (m³/s)
points | mean annual | summer monthly mean (May to Oct) | winter monthly mean (Nov to Apr) | minimum recorded daily discharge | period of record
Fort Providence | 4280 | 6330 | 2370 | 1040 (Apr 16, 1969) | 1943 to 1979 (continuous)
Fort Simpson | 6760 | 10400 | 2960 | 1520 (Mar 23, 1969) | 1943 to 1979 (continuous)
Norman Wells | 8550 | 13000 | 3860 | 1950 (Dec 26, 1979) | 1943 to 1955 (partial) 1962 to 1979 (continuous)
Arctic Red River | 9630 | 15300 | 3110 | 2230 (Dec 25, 1979) | 1972 to 1980 (continuous)
KITTIGAZUIT BAY
HUGHMALLIT BAY
YUKTOYAKTUK
Mackenzie Delta
ARCTIC RED RIVER
PT SEPARATION
FT McPHERSON
MACKENZIE RAMPARTS
FT GOOD HOPE
BANS BAULT RAPIDS
NORMAN WELLS
FT NORMAN
GREAT BEAR LAKE
Mackenzie Mountains
YUKON TERRITORY
NORTHWEST TERRITORIES
WRIGLEY
FT SIMPSON
FT PROVIDENCE
Mills Lake
Beaver Lake
BIG ISLAND
B.C.
ALTA
LEGEND
Sensitive Area
Main River
Subbasin Boundary
River profiles are approximate only and are plotted on the continuous river system length from the mouth of the Mackenzie River to the headwaters of the major tributaries
Elevation (metres-ASL)
Kittigazuit Bay
Mackenzie Delta
Peel River
Elevation 3.5 Metres
Arctic Red River
Approximate profile from Fort Good Hope to Kittigazuit Bay
Ramparts
Sans sault Rapids
Great Bear River
FORT GOOD HOPE
NORMAN WELLS
FORT NORMAN
WRIGLEY
McGern Island
Lord River
Green Island Rapids
FORT SIMPSON
Mills Lake
Providence Rapids
FORT PROVIDENCE
Great Slave Lake
River Profile
Mainstem Mackenzie River
(distance from Kittigazuit Bay, Mackenzie Delta)

Figure 2.43

Mackenzie River Subbasin

6. Mackenzie River Subbasin

The Mackenzie River starts at the western end of Great Slave Lake and flows as a river for 1410 km to the Mackenzie Delta. It traverses the final 240 km of its course through several major channels and innumerable smaller channels in the delta before reaching Mackenzie and Kugmallit Bays in the Beaufort Sea (Figure 2.43).

The largest identifiable channel, terminating at Kittigazuit Bay, an arm of Kugmallit Bay, was used to determine river length. The river is divided into four descriptive reaches for the purposes of this report:

- Great Slave Lake to Liard River
- Liard River to Great Bear River
- Great Bear River to Point Separation
- Mackenzie Delta.

Great Slave Lake to Liard River

Great Slave Lake is the major influence on this entire upper reach of the Mackenzie River. It moderates low and high flows, reduces temperature fluctuations, and greatly influences the timing of freezeup and breakup of the river. No major tributaries join the Mackenzie until the Liard River enters at Fort Simpson some 320 km from Great Slave Lake (Figure 2.44). This upper portion of the Mackenzie River has a low lying, nearly flat topography covered with muskeg, pothole lakes, and relatively slow meandering streams.

The water depth of the outflow channels from Great Slave Lake is so shallow that both the South Channel and Beaver Lake, which is merely a shallow widening of the river, have to be dredged for barge traffic. Along with Mills Lake, about 60 km downstream, Beaver Lake provides important waterfowl habitat (Figure 2.45).

The Mackenzie Highway ferry crosses the river about 10 km above Fort Providence. Just downstream of the ferry the 2.2 km wide river narrows down to half its width, forming the swift-running but non-turbulent Providence Rapids. The community of Fort Providence, established in the 1860's as a Roman Catholic mission, is located on the steep 15 m high north bank of the river just below the rapids. The river then widens again and forms Mills Lake, a shallow lake with a low, poorly defined shoreline.

Farther downstream the Trout River and Jean Marie Creek, two minor western tributaries, join the Mackenzie. They are described later in this section as sensitive areas. The river banks begin to rise in the lower third of this reach. The confluence of the Liard and Mackenzie rivers is marked by an imposing bluff, which was once considered as a possible site for the capital of the Northwest Territories. It is at this point that the Mackenzie River almost doubles in volume.

Sensitive Areas

Deep Bay, Beaver Lake, and Mills Lake These three areas are important for fall staging of waterfowl. The river freezes up much later here, because of the warmer water flowing from Great Slave Lake. In years of drought on the prairies, Mills Lake also becomes an important nesting area. Deep Bay on Great Slave Lake, and the North and South channels around Big Island, support large numbers of arctic grayling, northern pike and walleye. Parts of this area are important to the local population, as well as to the people of Hay River

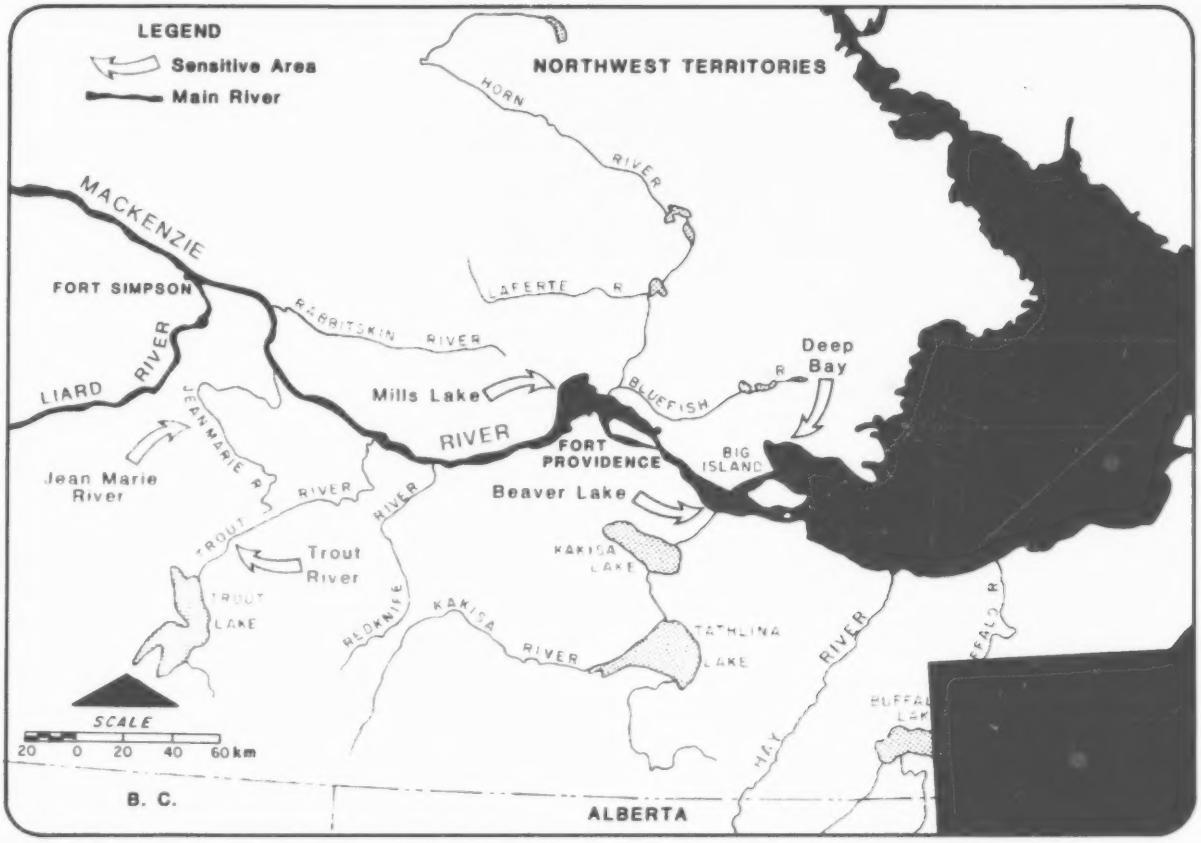


Figure 2.44

Mackenzie River

Great Slave Lake to Liard River

and Yellowknife, for waterfowl hunting, fishing, and trapping.

An environmental assessment of dredging a deeper navigation channel in the Mackenzie River concluded that the sport fishery of Beaver Lake would be adversely affected in the short term, but that the long-term impact could be positive. Dredging would not affect spawning grounds and the disturbance of nesting waterfowl would be minimal.

Trout River and Jean Marie River

Both Trout River and Jean Marie River rise in the Cameron Hills to the west of the Mackenzie and flow through the flat, lake-filled Great Slave Plain to the Mackenzie River. Fish populations are the most important and sensitive resource of these streams.

Jean Marie River is important for walleye which spawn in the upper and lower reaches during late May. The entire river is a major nursery for walleye and arctic grayling. Northern pike, whitefish, inconnu, and least cisco are also present. Economic species are fished heavily by residents of the Village of Jean Marie. Trout River is also a spawning and nursery area. Below the falls are spawning and nursery areas

for arctic grayling, northern pike, walleye, and longnose sucker; above the falls northern pike and longnose suckers spawn and arctic grayling have been found. The Trout River area has good sport fishing and recreation potential.

1 Start of Mackenzie River at Great Slave Lake
2 Beaver Lake
3 Deep Bay
4 N.W.T. Highway No. 3, from Mackenzie Highway to Yellowknife
5 Mackenzie Highway
6 Fort Providence
7 Kakisa Lake
8 Mills Lake

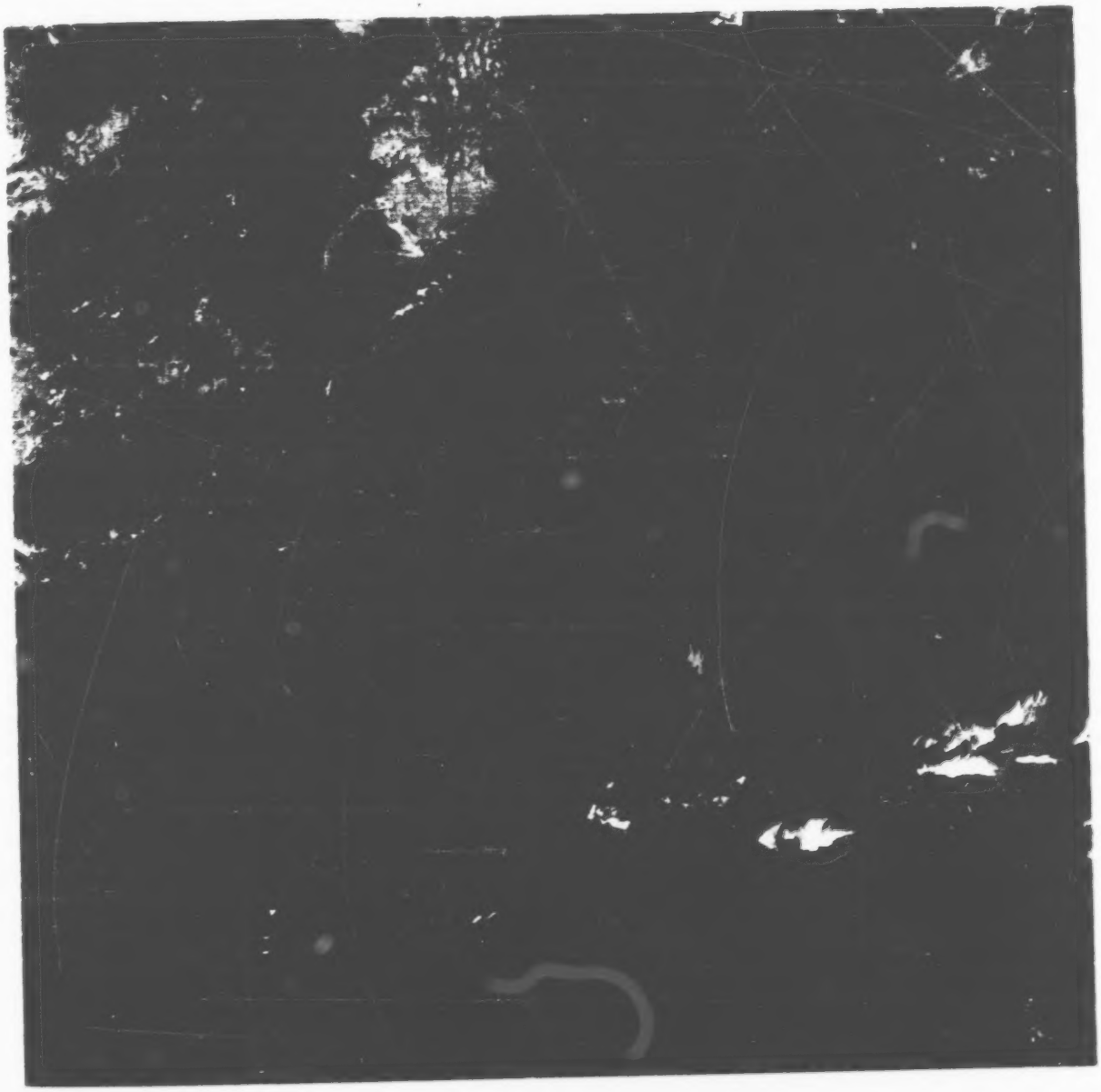


Figure 2.45
Mackenzie River
at Great Slave Lake

Liard River to Great Bear River

A number of sizeable tributaries enter the Mackenzie River in the 450 km reach from the confluence with the Liard River to the confluence with the Great Bear River at Fort Norman (Figure 2.46). These rivers include the North Nahanni, Redstone, and Keele Rivers from the west, and the Willowlake and Ochre Rivers from the east. The western tributaries are relatively warm and turbid, and the eastern tributaries cold and clear.

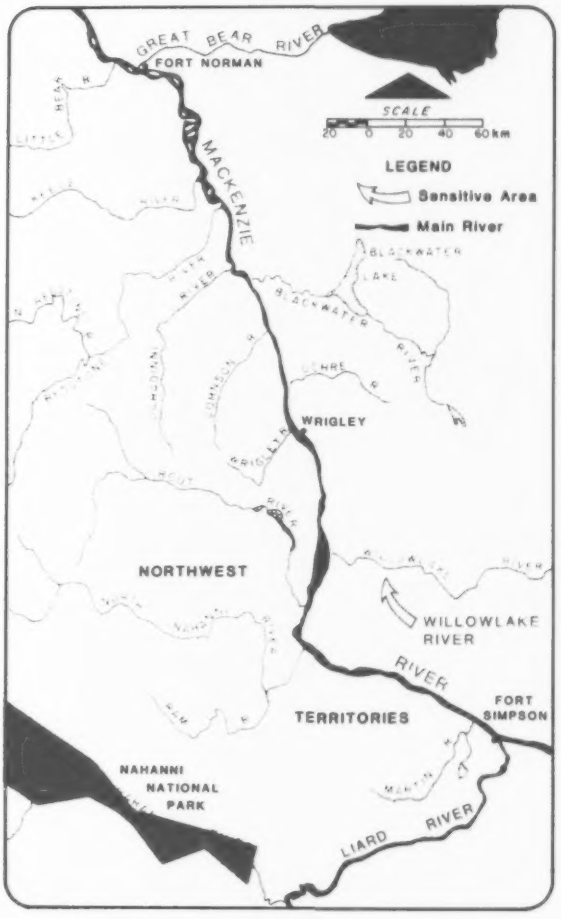


Figure 2.46
Mackenzie River
Liard River to Great Bear River

At the confluence with the Liard River, the Mackenzie waters are pushed toward the northern shore by the strong Liard inflow (Figure 4.7). Its warm and silty waters flow unmixed side by side with the cold and clear Mackenzie waters. The line of demarcation is clearly visible and has been observed as far as 300 km downstream.

Sensitive Area

Willowlake River The Willowlake River rises at Willow Lake and flows west to meet the Mackenzie River between Wrigley and Fort Simpson. Fish are the most important resource of the Willowlake River, and arctic grayling is the key species present. A small fishery operates at the mouth of the river and fishing camps occur along its length. The river is part of a traditional canoe route used by residents of Fort Rae and Lac La Martre for travel to Fort Norman.

Great Bear River to Point Separation

The Great Bear River is the largest of the east bank tributaries. Its waters resemble those of the upper Mackenzie River in temperature and clarity, as both rivers drain a large cold lake. However, where the Great Bear River joins the Mackenzie, it is much colder than the Mackenzie River and free of sediment. The Great Bear River waters do not mix with the Mackenzie waters for a long distance downstream. This phenomenon, which is also experienced with the Liard River, is a distinct feature of the Mackenzie River system.

The most difficult and dangerous section of the Mackenzie River for navigation is the Sans Sault Rapids, about 200 km below Fort Norman (Figure 2.47). These rapids are so named because of the lack of white

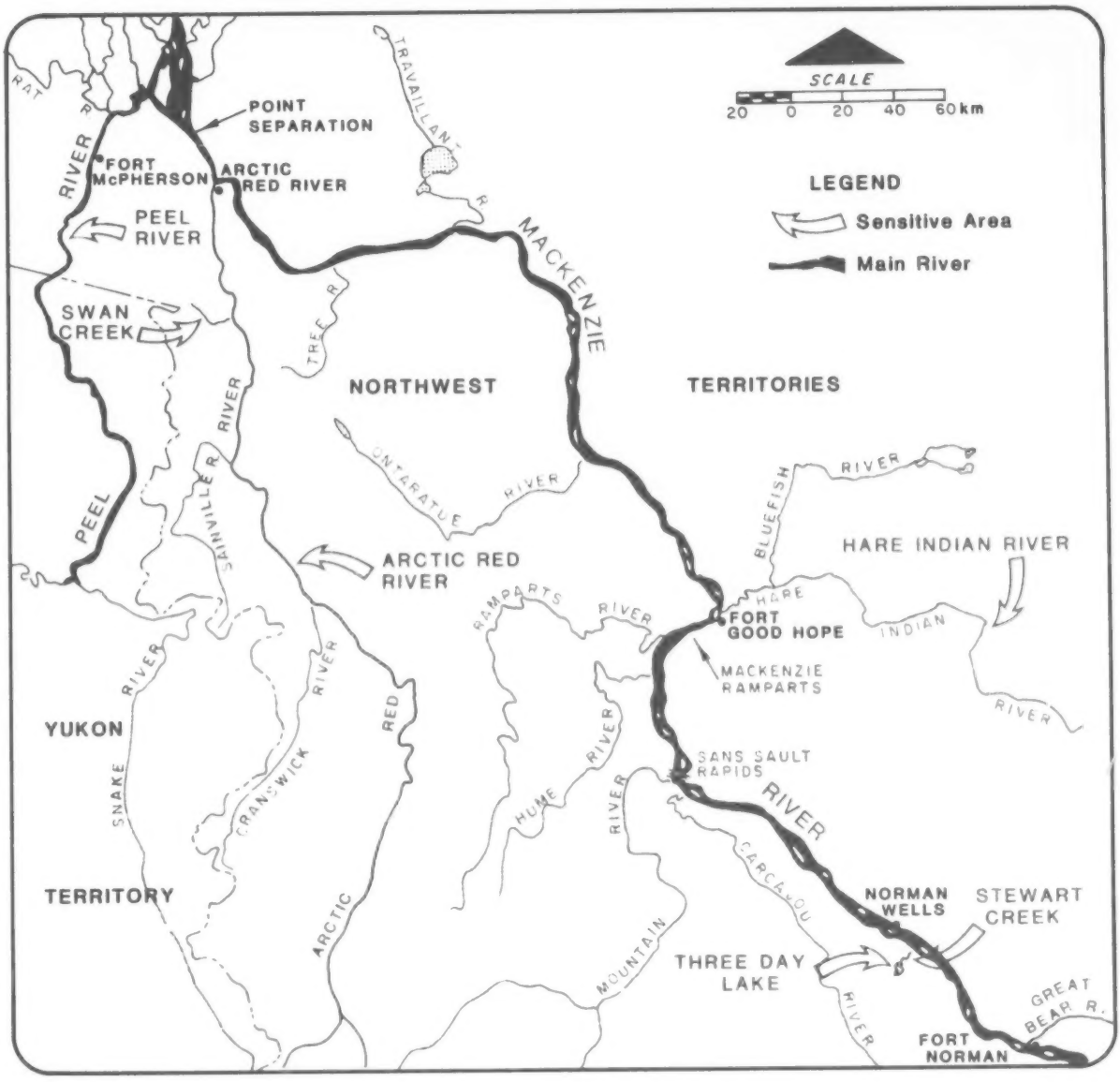


Figure 2.47
Mackenzie River
Great Bear River to Point Separation

water, but they are still dangerous to small craft because of the standing waves at the head of the rocky ledges forming the rapids.

The most dramatic river stretch occurs about 70 km farther downstream and just above the historic settlement of Fort Good Hope, at The Ramparts (Figure 2.48). The vertical walls form a two kilometre long canyon, varying in width from 400 m at the upstream end to more than 1300 m at the downstream end. In the canyon itself the river gradient appears steep, and gives a false impression of

Figure 2.48
The Ramparts
Mackenzie River

a fast current. This is an optical illusion caused by the limestone beds dipping in an upstream direction against the flow of the river. In reality, even where sheer bluffs confine the river to its narrowest width of 400 m, the current is slower than that encountered just above The Ramparts.

The old settlement of Fort Good Hope is the centre of activity in The Ramparts area. The settlement was originally established in 1804 as a post of the North West Company. In 1821 it passed into the hands of the Hudson's Bay Company when the two companies amalgamated. Subsequently the post was moved to Manitou Island, then to its present east bank site after the disastrous breakup of the ice cover on the Mackenzie River in 1836. In the spring of that year, an ice jam in The Ramparts suddenly gave way, unleashing a flood of water and ice that swept over Manitou Island and forced the occupants of the post to seek higher ground.

Beyond Fort Good Hope the Mackenzie River continues on its northwesterly course and is joined by the Arctic Red River just 20 km above Point Separation. At Point Separation the Mackenzie divides into the maze of distributary channels of differing lengths, flow rates, and gradients which make up the Mackenzie Delta.

Sensitive Areas

Three Day Lake – Stewart Creek This tiny watershed discharges on the west side of the Mackenzie River between Norman Wells and Fort Norman. It is a critical area in the life cycle of a relatively large population of arctic grayling.

Hare Indian River The Hare Indian River originates near Great Bear Lake and flows west to join the Mackenzie near Fort Good Hope. This river is important as a spawning and nursery area for arctic grayling and longnose sucker. White sucker, round whitefish, humpback whitefish, northern pike, and white sucker are also found.

Arctic Red River The Arctic Red River originates in the Mackenzie Mountains and flows 370 km north to join the Mackenzie River at the Village of Arctic Red River (Figure 2.49). The area is highly productive for beaver, moose, muskrat, and waterfowl. The river is a spawning area for inconnu and humpback and broad whitefish. Domestic fishing, hunting, and trapping are

This winter picture brings the two ranges delineating the delta into particularly good relief.

1 Caribou Hills
2 Richardson Mountains
3 Arctic Red River at confluence of Arctic Red and Mackenzie Rivers
4 Fort McPherson
5 Peel River: it loses much of its water to the southwestern part of the delta, which it dominates, and barely connects with a side branch of the Mackenzie River.
6 Inuvik
7 Aklavik
8 Rat River

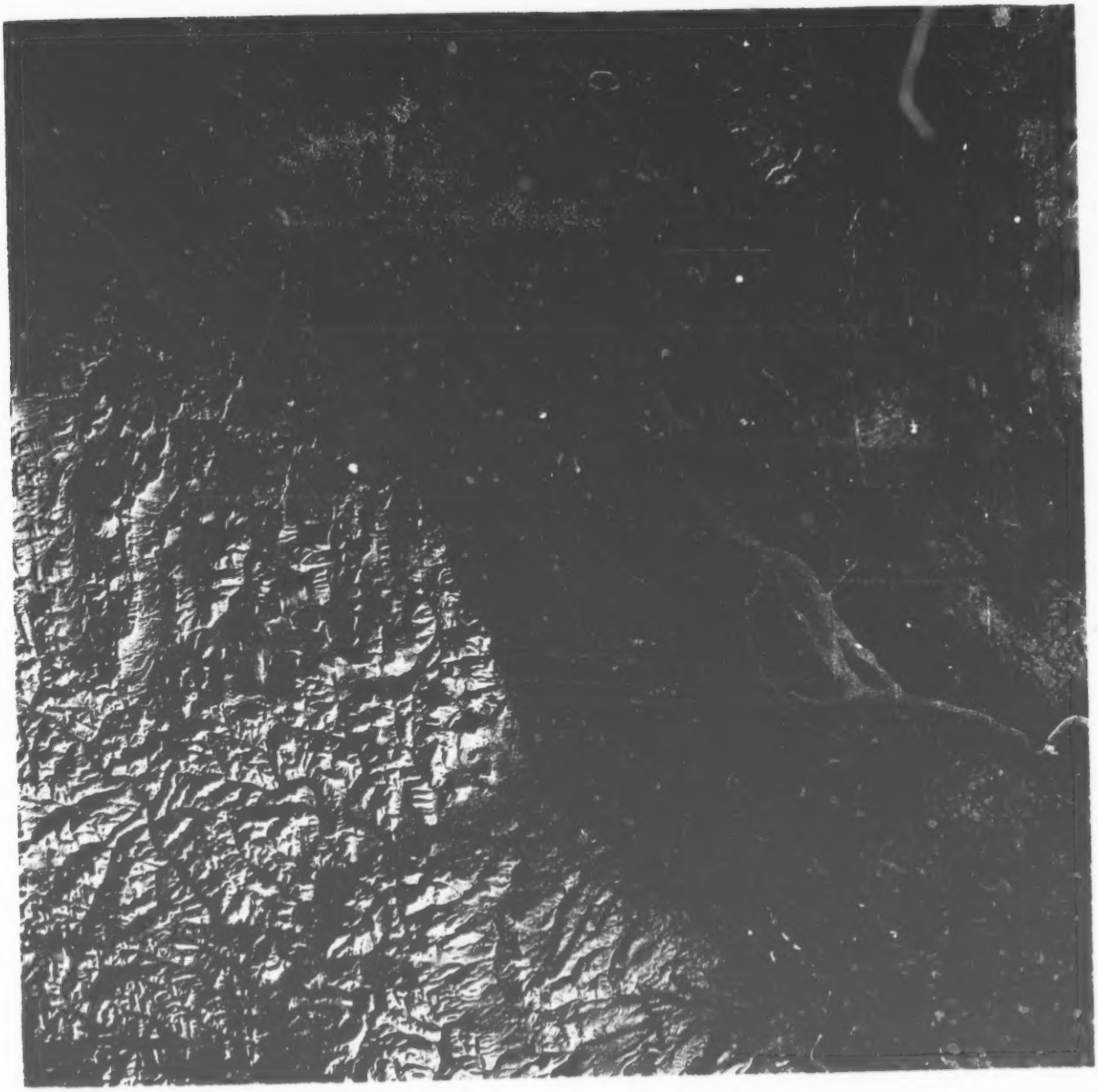


Figure 2.49
Mackenzie Delta

important to the residents of Arctic Red River. The river contributes a large sediment load to the Mackenzie during summer storms.

Swan Creek Swan Creek drains a system of four lakes, collectively known as the Fishing Lakes, and flows into the Arctic Red River. This watershed is important to arctic grayling all year. It is also a spawning area for longnose sucker and northern pike and is a domestic fishing area for the residents of Arctic Red River.

Mackenzie Delta

The Mackenzie Delta (Figure 2.50)is the most significant northern delta on the North American continent and plays a crucial role in Canada's arctic ecosystem. It is the tenth largest delta in the world, and among arctic deltas is second only to the Lena River Delta in Siberia. The Mackenzie Delta also plays a continental role for migratory birds as a major terminus for the Pacific and Central Flyways.

The Inuit have lived in the delta since the earliest days of their migration eastward from the Bering Strait. Hunting, trapping, and fishing of a wide variety of species continue to be very important to their livelihood and way of life. Two permanent communities, Inuvik and Aklavik, are located within the delta. Tuktoyaktuk at the northeastern edge of the delta serves as the transportation terminus for the entire western arctic.

Geomorphology The Mackenzie Delta is an estuarine delta with poorly developed levees, formed largely from sediments transported by the Mackenzie River over the last 13 000 years. The southwest sector also receives sediments from the Peel and Rat Rivers. The major channels seem to have changed little in the last century.

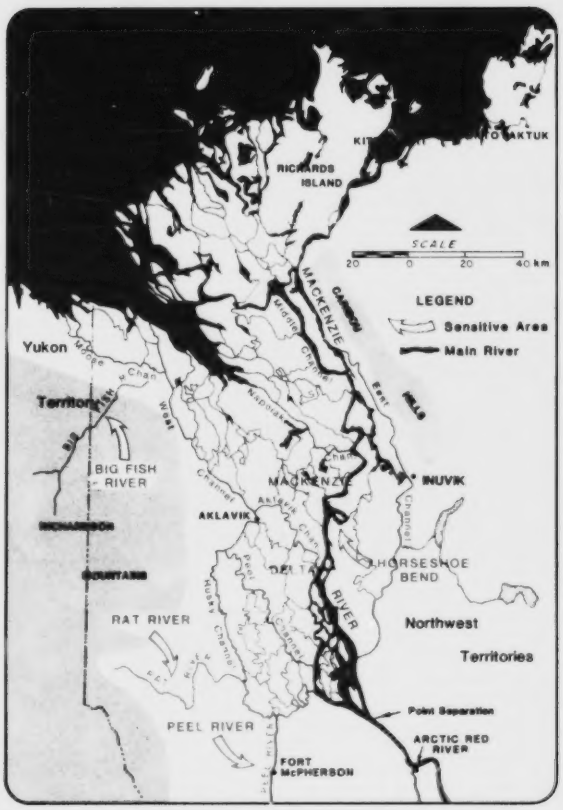


Figure 2.50
Mackenzie Delta
Point Separation to Kittigazuit Bay

The Mackenzie Delta continues to extend into the Beaufort Sea (Figure 2.51). The offshore deposition of sediments and the propagation of seawater into the delta are influenced by the volume of river flow, and the currents, wind, and ice conditions in the Beaufort Sea.

Landscape The Mackenzie Delta is a complex area and includes the remnants of earlier deltas. The present delta is flat and dotted with numerous lakes, ponds, and river channels, but also contains land

The striking sediment plume extending into the Beaufort Sea attests to the scale of erosion and sedimentation in the Mackenzie Basin. The biggest sediment load recorded was 24 million tonnes per day, on August 12, 1974. The photo also shows the many lakes and channels in the delta.

1 Mouth of Mackenzie River at Kittigazuit Bay
2 Tuktoyaktuk
3 Kugmallit Bay
4 Mackenzie Bay
5 Kendall Island Migratory Bird Sanctuary
6 Big Fish River
7 Aklavik
8 Horseshoe Bend

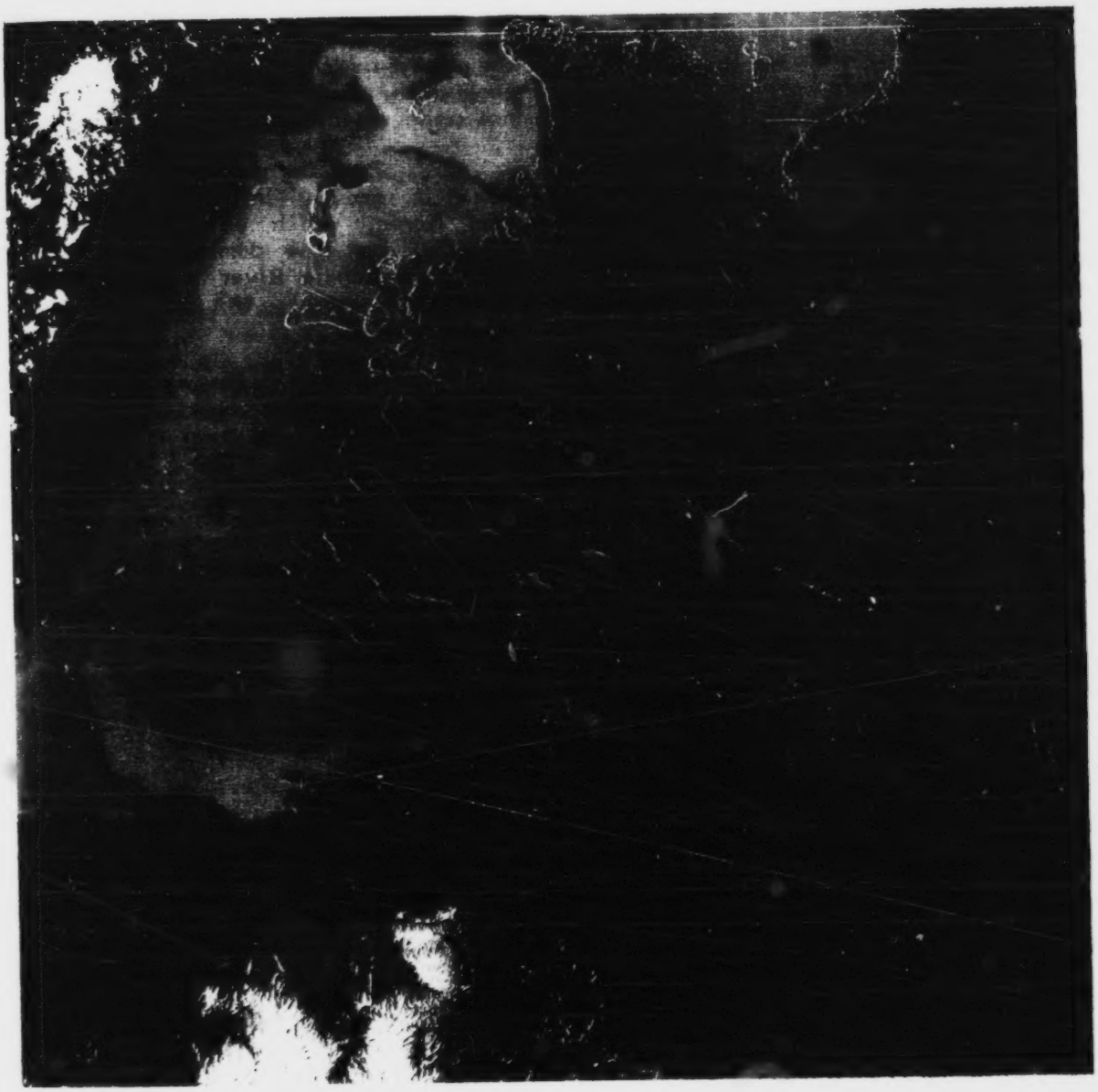


Figure 2.51
Mackenzie Delta

varying from stable forested areas to tidal flats. It is laced with a maze of meandering channels. The Richardson Mountains on the west and the Caribou Hills on the east sharply delineate the delta (Figure 2.49). Boating on the Mackenzie River is popular and camping is possible on the islands, but the maze of channels and the scarcity of landmarks make delta navigation away from the main channels difficult.

The ground is dotted with tundra polygons, which are particularly abundant in the southern part of the delta and are easily recognizable from the air. An even more conspicuous frost feature is the pingo, a typically abrupt, conical hill, some 1400 of which are scattered over the older, eastern sections of the delta in one of the densest concentrations in the world (Figure 2.52).

Typically, the pingos rise in a water-filled depression, a lake, or marsh on the older delta. Most have simple, smooth outlines and are oval in ground plan. The summits of the largest tend to be cratered or creviced, somewhat resembling opening buds. The more outstanding specimens may be 50 m high and 200 m in diameter.

Hydrology Relatively little is known about the hydrology of the Mackenzie Delta. The basic data are inadequate and the linkages between the many hydrological, physical, and ecological aspects of the delta are not understood.

The southwestern part of the delta is greatly influenced by the Peel River, which enters the delta directly; but the dominant influence is the Mackenzie River which asserts itself right across the delta farther downstream.

Ice covers the waters of the Mackenzie Delta for eight months of the year. The first sign of breakup occurs in April when traces of

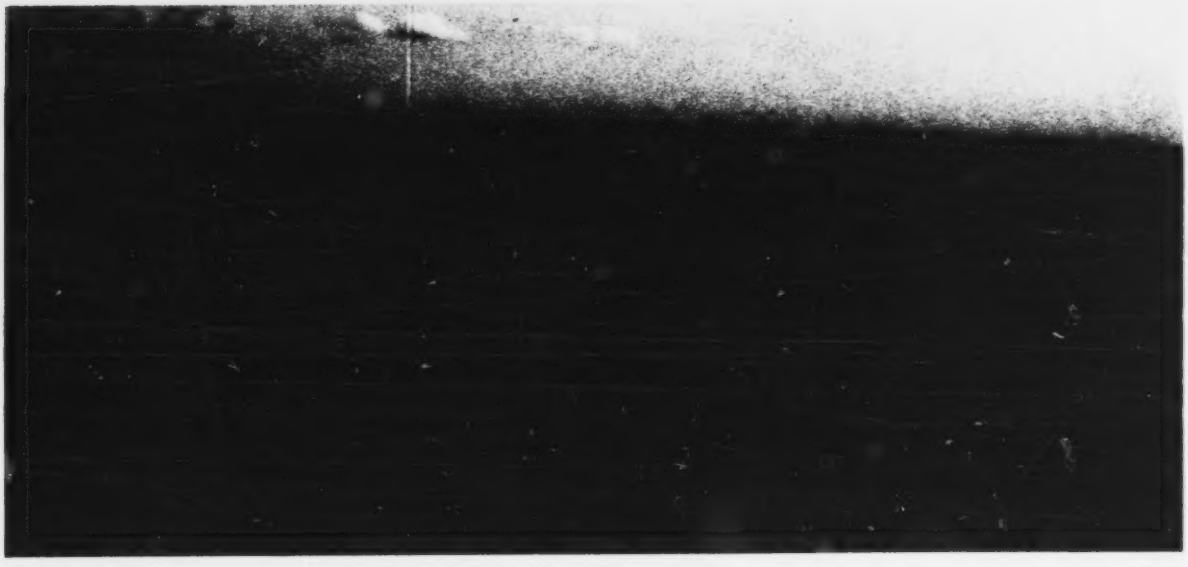


Figure 2.52
Pingo
Mackenzie Delta

meltwater can be seen along the channel edges. The first ice movement occurs about one week before peak spring water levels.

Vegetation Vegetation zones within the Mackenzie Delta from south to north are: boreal forest (its northernmost extension in Canada), forest-tundra transition, and tundra. The wet, flat alluvium and islands at the mouth of the delta are unvegetated mud flats. Other broad areas are dominated by a single species of horsetail or sedge. Drier hummocky areas have developed a community of low willows, sedges, and horsetails.

Sensitive Areas

Peel River The Peel River originates in the Ogilvie Mountains and empties into the Mackenzie Delta 65 km south of Aklavik. The lower portion of the watershed is an important breeding area for Canada geese and a variety of ducks. It provides an important habitat for muskrat and beaver and supports populations of Dall's sheep, woodland and barren-ground caribou, grizzly bear, marten, lynx, wolverine, and moose. Large upstream migrations of least cisco and arctic cisco occur in the Peel during July and August and arctic char also range into the Peel River and Peel Channel. The Peel watershed has traditionally supported people from Fort McPherson and some residents from other Mackenzie Delta communities.

Rat River and Big Fish River The Rat and Big Fish Rivers originate in the Richardson Mountains and flow eastward into the Mackenzie Delta. Steep banks and cliffs along the shorelines of both rivers provide attractive nesting sites for raptors such as peregrine falcons, gyrfalcons, golden eagles, bald eagles, and osprey. A variety of big game species including grizzly bear, barren-ground caribou, and moose occur in both watersheds. These areas also support the northernmost population of Dall's sheep in Canada (Figure 2.53).

Figure 2.53
Dall's Sheep

Arctic char are the most abundant of the 14 species of fish caught in the Rat River. The char spawn in Fish Creek in September and October. The Rat River and Big Fish River watersheds are important to residents of the Mackenzie Delta all year for hunting and trapping. The Rat River is also a proposed International Biological Program (IBP) site.

Mackenzie Delta Deltas are among the most complex ecosystems. Understanding the Mackenzie Delta is a major long-term task due to the perplexing array of ecological interrelationships. The effects of arctic conditions in this area further

complicate the relationships. It is evident that the many specialized and local studies of recent years have barely begun to increase man's comprehension of the Mackenzie Delta (Table 2.3). A concerted study of the delta is one of the recommendations made in Chapter 7.

Table 2.3
Mackenzie Delta Study Needs

WATER	flows, levels, sediment (erosion, deposition), water quality, temperature, flooding (timing, duration, extent, stage), mixing zone
SOIL AND VEGETATION	soil and vegetation types, habitats, nutrients, rates and types of plant succession, role of permafrost
CHANNELS AND LAKES	types, stability, geometry, permafrost
ICE REGIME	ice thickness, freezeup and breakup (timing, mechanics, flows), ice jams
CLIMATE	influence on freezeup and breakup, vegetation, permafrost
AQUATIC ENVIRONMENT	primary and secondary production, food web, habitat, fresh-salt water interactions
WILDLIFE	populations (muskrat, beaver, terrestrial furbearers, waterfowl, marine mammals, ungulates, birds), breeding and staging, habitat, food supply
MARINE ENVIRONMENT	various aspects
INTERRELATIONSHIPS	between marine and river environment, as well as among the individual aspects mentioned above

The main features of the delta are described above. The delta is considered an important and very sensitive area for its population of birds, waterfowl, mammals, and furbearers. Upstream developments in this huge basin would ultimately be felt in the delta; however, determining what these effects will be is a major challenge. Development of the Beaufort Sea oil and gas resources nearby could affect the delta directly. It is evident from the following description of the delta as habitat for various species that its significance extends far beyond the area itself.

Millions of birds of some 139 species are found in the Mackenzie Delta - Beaufort Sea area. Large numbers of waterfowl converge on the delta during annual migrations. For many, the delta is a short stop on their way to and from nesting areas farther north. The coastal strip, about 25 km wide, is considered to be the most important delta area for migratory birds.

In the outer Mackenzie Delta nesting whistling swans reach the highest concentrations recorded in Canada. The outer delta east of the Kendall Island Sanctuary is a critical habitat for nesting and moulting waterfowl including whistling swans, white-fronted geese, sandhill cranes, and various shorebirds. Several species of ducks nest in the delta. The Hudsonian godwit, a rare shorebird, is found in relatively concentrated numbers. Rough-legged hawks, bald eagles, and merlin nest in the delta. Peregrine falcons nest in the Caribou Hills near Inuvik.

The most important marine mammals to the local economy of the delta are white or beluga whales. Approximately 4000 to 5000 white whales move into the warm estuarine water in June and July, probably for calving. This relatively small group of white whales is the only white whale population in the western Canadian Arctic. Although the function of the Mackenzie estuary in the life history of the white whale is not understood, it is believed to be critical to the survival of the population.

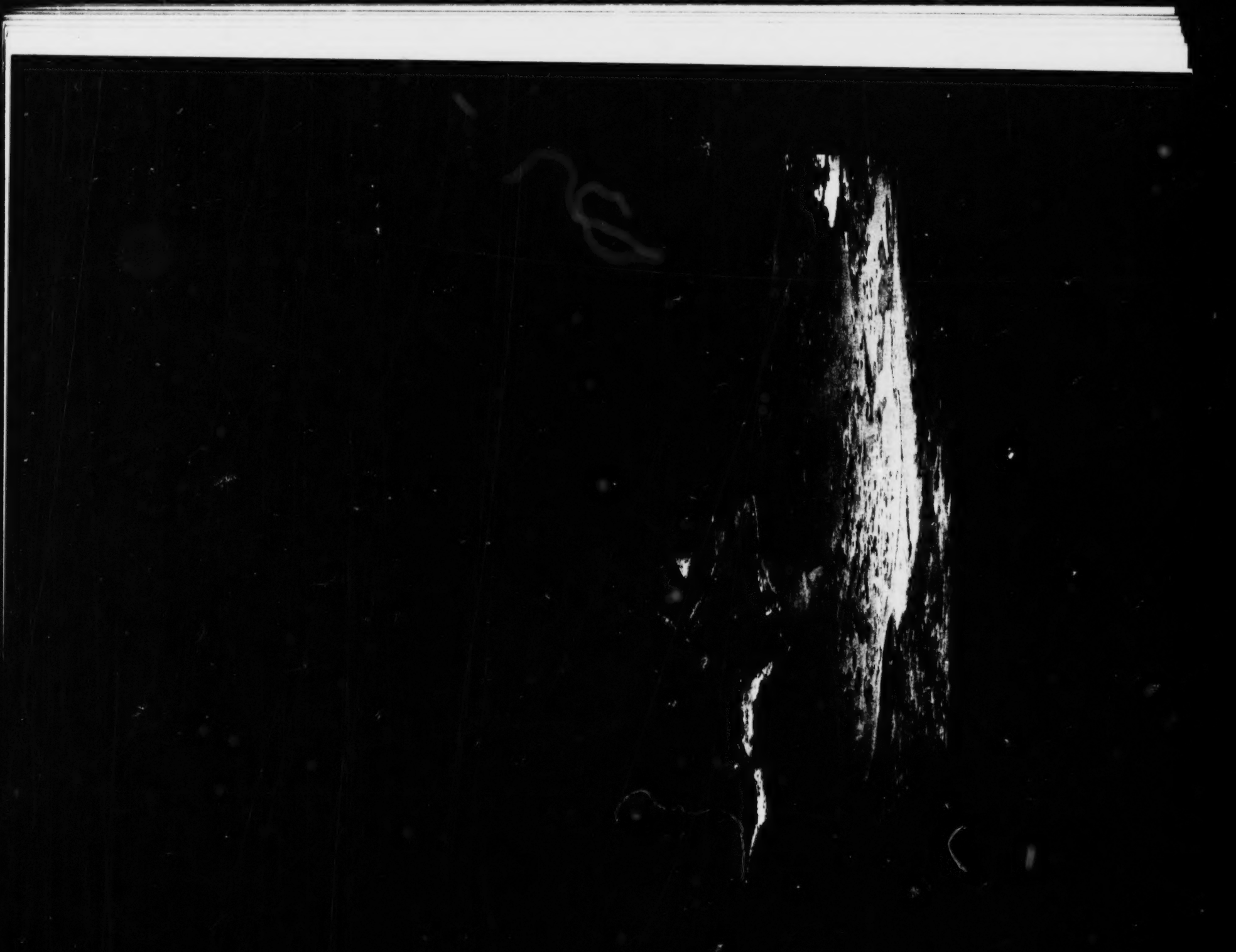
Muskrats in the Mackenzie Delta restrict their dens to the river banks. The remainder of the delta, except for Richards Island, is unsatisfactory habitat. Beaver habitat in the delta is restricted to areas with poplar and willow. Overuse of habitat occurs frequently and colonies may move every one or two years.

The Mackenzie Delta and its estuaries are a complex series of aquatic habitats (Figure 2.54). Many of the fish species that use the delta have complex life histories and migration patterns. Species present include freshwater forms, which stay in the delta all their lives, and anadromous forms. Anadromous fish hatch and spend various periods of their lives in fresh water. They then move into the ocean where they remain until maturity. As adults they return to fresh water and embark on annual or biannual spawning migrations.

Over 30 species of fish frequent the freshwater habitat. Between mid-August and early October there are major spawning runs of inconnu, humpback whitefish, broad whitefish, and least cisco. These fish travel to spawning areas in the Peel and Arctic Red Rivers, and other upstream tributaries of the Mackenzie River. Beginning in November and following freezeup, fish return to wintering areas after spawning.

Horsehoe Bend Horseshoe Bend is one of the few locations within the Mackenzie Delta that has been identified as a spawning area for humpback whitefish and possibly broad whitefish. Northern pike and inconnu are also present.

Figure 2.54
Meander Scrolls
Mackenzie Delta



A. The Dynamic Nature of Alluvial Sites

B. Aggrading Processes

C. Degrading Processes

D. Successional Vegetation

E. Use of Alluvial Habitats by Plants and Animals

F. Effects of Alluvial Vegetation on Fluvial Processes

G. Evaluation and Conclusions

Alluvial Ecosystems

3

Water is one of the prime shapers of the landscape. It wears down mountains and erodes the earth wherever there is sufficient flow to carry away soil particles. Erosion can be quite dramatic and therefore attracts far more public attention than the deposition of the sediments farther downstream in a drainage basin. Erosion tends to occur in areas of greatest visual contrast and sharpest topographic relief, where it may remove valuable river frontage and undermine and destroy highways, bridges, and buildings (Figure 3.1). By contrast, the waterborne sediments are laid down quietly and gradually as low-relief "alluvial" deposits. This occurs in low-lying areas along stream channels (Figure 3.2) and in deltas where they are hardly noticed and seldom interfere with man's activities. Yet it is precisely in these alluvial areas that plant and animal life flourish in great variety. This chapter highlights the physical and biological processes that make alluvial ecosystems possible. A more complete discussion is found in Supplement 2.

A. The Dynamic Nature of Alluvial Sites

The dynamic nature of alluvial sites is emphasized by all who have studied such habitats. Each site is

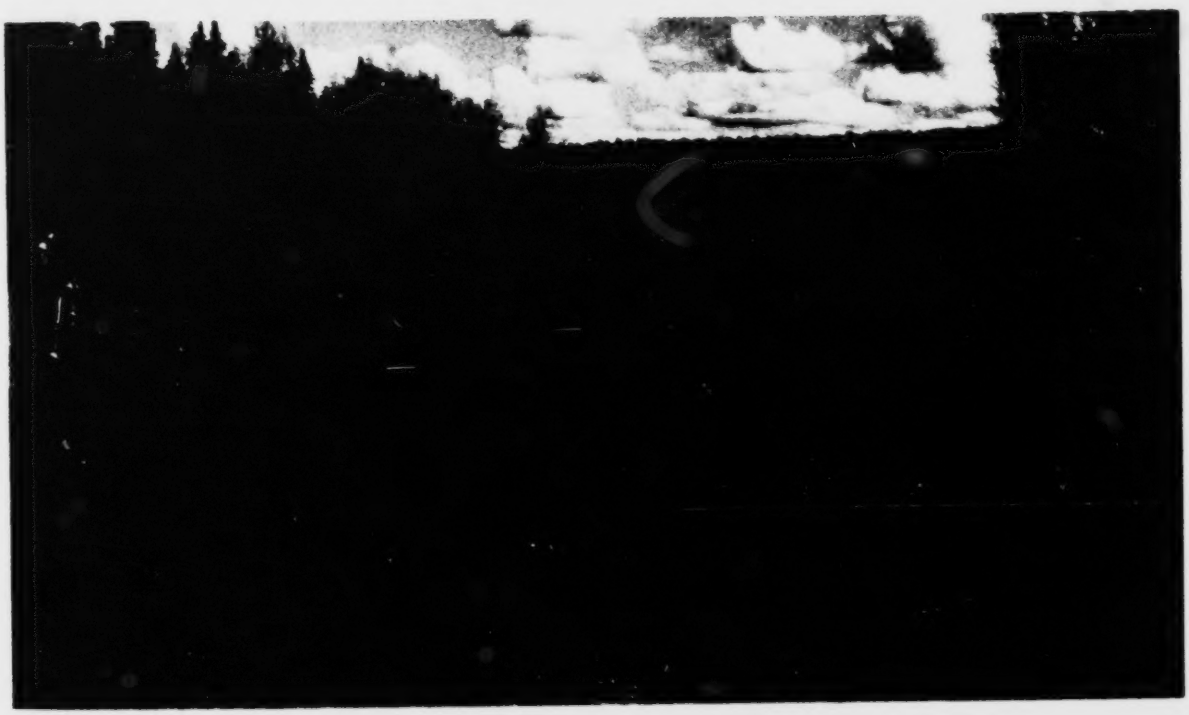


Figure 3.1
Severe Bank Erosion
Muskwa River

Figure 3.2
Islands and Point Bars
formed by sediment deposition

subject to change: first by aggrading processes as sediment is deposited; then by a combination of physical and biological influences through the development of a series of plant communities and associated animal species; then eventually by destructive physical forces that either erode alluvial sites or cover them with new layers of sediment. Although the factor of change is central to the productivity of alluvial sites, there is also a relative overall stability within alluvial ecosystems.

The apparent contradiction between continuous change and relative stability can be understood if one makes a distinction between alluvial sites and alluvial ecosystems. Alluvial site refers to a point location at which a process of aggrading or degrading is occurring at any given time. Alluvial ecosystem refers to a complex of alluvial sites, the components of which each change with time, but which in combination provide a relative stability in any given floodprone area by providing a more or less constant set of habitats for plants and animals. Although features found at a specific site differ over a period of years, the general nature of a delta or river valley remains in a state of disclimax equilibrium.

Physical and biological processes in alluvial sites of the Mackenzie River Basin are strongly influenced by the fact that the spring breakup is the major hydrologic event each year. Not only do high water levels occur during the breakup period, but also some of the most severe erosion along river channels occurs then. After the spring breakup peak runoff often occurs. Large volumes of

river ice jam at river bends and in shallow shoals; such jams produce upstream flooding. Occasional summer rainstorms in the Mackenzie River Basin produce floodwaters higher than the spring freshet, especially on rivers with mountainous headwaters. In general, rivers of the basin are characterized by low summer, fall, and winter water levels that are broken only by high water levels during the spring breakup, during the period of maximum runoff, and during intermittent and unpredictable summer storms. The yearly occurrence of the spring breakup makes it the dominant hydrologic event.

The height of floodwater is not the only feature of the spring breakup period that is important to plant and animal communities. Spring breakup also influences water temperature and the length of the growing season in the lower Mackenzie River and its delta. A rapid increase in water temperature results from the physical action of floodwater in lifting, breaking, and removing the winter ice cover. Floodwaters also contain large sediment loads. Nearly half of the delta area is covered by lakes and channels (Figure 2.49) upon which sediment is deposited by floodwaters. This causes the solar radiation-deflecting ice and snow to be covered by radiation-absorbing dark-colored sediment which encourages faster melting. As a result, the connected lakes and oxbows adjacent to the river and delta channels are free of ice about a month before areas adjacent to the delta. This relatively rapid warming lengthens the growing season and allows the growth and establishment of white spruce and balsam poplar. In the delta, this creates one of the most northerly extensions of the boreal forest in North America. These plant communities provide important wildlife habitats which are not available in the surrounding areas.

Following spring breakup, the floodwaters recede by evaporation, percolation, and outflow. This period is referred to as drawdown and is thought to be ecologically important, although this is not well documented. It is known that timing of drawdown during the summer growing season is one factor that determines which plant species can establish themselves in exposed areas. Changes in flow regime

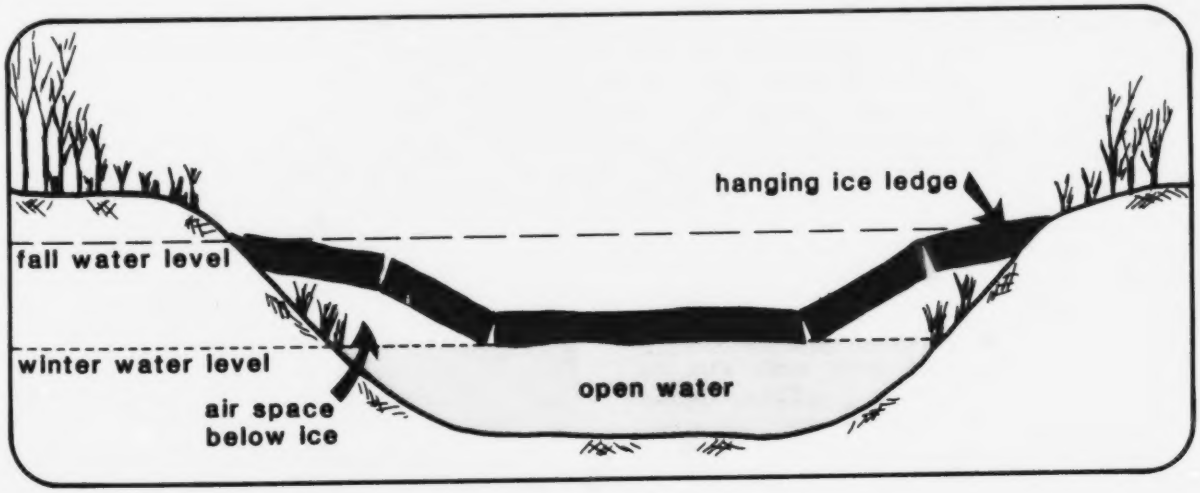


Figure 3.3
Hanging Ice Ledges
resulting from winter drawdown

that do not influence maximum flood levels but do influence duration of floods and rate of drawdown can have major effects on plant and animal communities. As an example, the physical changes that accompany winter drawdown can be of particular biological significance for some species. Channels and streams freeze in the fall prior to reaching their lowest levels for the year. When water levels drop, the ice drops to rest on the water, except at the shore where an ice ledge remains above a protected air space (Figure 3.3) . Muskrat may use the air spaces to feed on horsetail exposed by the receding water. However, when using the air spaces below the ice, muskrat are vulnerable to predation from mink which also forage under the ice.

B. Aggrading Processes

Every place of water erosion is matched by a place of sediment deposition (Figure 3.4). High water levels, ice jams, and ice-shove ridges are among the more dramatic physical aspects associated with the spring breakup period. However, the less dramatic but continuous erosion and rebuilding of alluvial landforms in river channels and in deltas are the dominant forces.

Changes in land surface and drainage occur so rapidly in alluvial sites that it is difficult to think of them except in terms of successional development. A major factor causing ecological change is the increasing elevation of surfaces over time due to deposition of alluvium. This deposition has three important effects: the internal drainage of soils increases with height above the river; the period of time that sites are under water during flooding is reduced with increasing height above the river; and the yearly amount of sediments added to the surface decreases with height above the river.

Island building, point bar formation, levee building, and general deposition of sediment over the surfaces of floodplains (Figure 3.2) and terraces are the prime building steps associated with floodwaters. Specialized landforms may be formed in alluvial areas, including ice-shove ridges along portions of stream channels subjected to repeated ice jams, small reverse deltas built into delta or floodplain lakes that are joined to a river by a connecting channel, or wind-deposited layers of mineral soil that may be shifted from channel edges during dry periods of low water.

The physical mechanisms by which terraces, floodplains, levees, islands, or point bars are built are too complex to summarize here. How-

Figure 3.4
Sediment Deposition
near mouth of Archibald River

ever, a brief account of the point bar environment (Figure 3.5), which has been documented in considerable detail within the Mackenzie Basin, shows the biophysical links between fluvial building processes and subsequent biological events. Surface water near the concave bank (where erosion occurs) plunges downward and is directed along the bed of the channel toward the convex bank. This cross-channel flow is called helicoidal flow and results in coarse bed materials being swept laterally to the convex or inside bank of the channel where they are deposited to build up a point bar. As sediment buildup enlarges point bars, their crests eventually surpass normal flood levels. Once the physical constraints of flooding and high sedimentation rates have been reduced, a distinct plant community of balsam poplar develops. Point bars in the delta are built mainly during the annual mid-May to mid-June flood period; therefore, their heights are usually coincident with average flood stage, which tends to be about 3.5 m above mean summer channel level.

As a point bar extends itself into a meander curve, a series of alternating arc-shaped ridges and depressions marks the successive, individual depositions (Figure 3.5). The depressions, located inland from each successive point bar, impound local runoff until they eventually fill with fine sediments deposited during the flood stage. These are called meander scroll depressions. Meander scroll pools are attractive habitat for beaver because of the natural cover of balsam poplar on nearby point bars (Figure 2.54). This is one example of the links that may exist between processes of fluid dynamics, sedimentation, sediment sorting, vegetational development, and wildlife occupation of alluvial ecosystems.

The amount of organic matter incorporated in the buildup of delta surfaces has not been studied in detail. Organic matter would be a relatively greater component of deposition in regions of continuous permafrost than in warmer climates because decomposition is arrested when perennially frozen ground prevails. In the Mackenzie Delta the flood stage brings organic debris that ranges from large logs to microscopic particles. There have been estimates that organic matter makes up as much as 25% of the total volume of silt exposed in channel

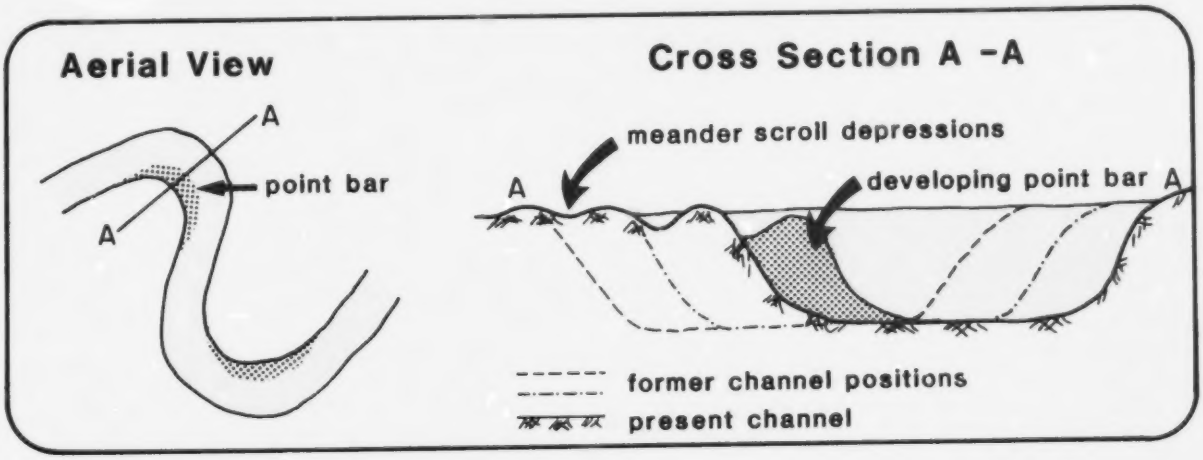


Figure 3.5
Point Bars and Meander Scroll Depressions

banks of the delta. Such estimates indicate the potential importance of nutrient re-deposition during floods. As outlined in a later section of this chapter, new plant growth starts on freshly deposited alluvium.

River banks and delta areas are ecologically classed as active, semi-active, or inactive depending on the degree or intensity of deposition processes. The active area, involving channels, point bars, levees, and plains surrounding open-basin lakes, is directly affected by flooding. The semi-active area, composed of perched basins and cut-off stream channels, is not directly connected with the main hydrologic system, but is recharged by overland flow of water during flooding. The inactive area, made up of closed basins, old meander scrolls, and back swamps, is higher in elevation and is influenced by flooding only at extremely high water levels. Because inflow of nutrients depends heavily on silt in floodwaters, the active areas have higher nutrient levels than the inactive areas.

Figure 3.6
Ice Rafts
showing ice scour

C. Degrading Processes

Some features of specific alluvial sites are developed and maintained by erosive forces. For example, when ice flow during spring flooding is hampered by a bend or some other constriction in a channel, rafts of ice may be pushed along the bank several metres above maximum flood levels. Pressure exerted by the moving ice scours away vegetation and soil (Figure 3.6). The result is a ridged zone of poorly developed vegetation that remains in a state of early successional development along the slopes of river channels where ice rafts are lodged each spring. Such ice-scour zones occur throughout the Mackenzie River Basin on a variety of alluvial landforms. In some areas ice scour produces boulder or gravel pavements along the river. Scattered willow and a few herbaceous plants are the only vegetation here. However, even such barren-looking areas provide habitat for some wildlife. A few species of birds such as Canada geese and spotted sandpiper nest in ice-scour zones.

Thermokarst lakes are a special erosive feature of the older parts of the Mackenzie Delta. Levees surrounding such lakes are underlain by permafrost, although the lakes themselves have a mean annual temperature above freezing. The levees are therefore continually eroding into the lakes as ice in the silts and clays is thawed by heat transmitted from the water. Because of the erosion, there

is little or no aquatic vegetation on the margins of thermokarst lakes.

Ice action on some delta channels exerts a mechanical control over some plant communities. It shears off the tops of shrubs as well as the above- and below-ground parts of plants that reproduce from underground stems. Ice action may also remove large amounts of sediment from levee slopes, preparing the way for fluvial erosion of the partially bared slope once the soil melts. Repeated ice scouring and water erosion may undercut the channel bank, leaving an unstable ledge that cannot support its vegetation and which eventually falls into the channel.

The Beaufort Sea coast, including outer parts of the Mackenzie Delta, is subject to rapid erosion. Summer storm surges accelerate the process. Shoreline retreat during a major surge may be as much as 20 m. Too few surges have been recorded in the Beaufort Sea to quantify their long-term effects on deltaic processes, but the continued seaward extension of delta landforms is known to be counteracted by the erosional forces of storm surges and longshore currents.

Erosion caused by floods that follow intense rainstorms in summer may exceed the erosive effects of the spring breakup, in part because storm floods consist of warmer water acting on at least partially thawed soils. The effects can include complete removal of small channel islands and whole stands of trees. Storm floods are a more significant cause of flood-plain change on braided mountain streams than are spring floods.

The relatively high primary productivity of alluvial sites is thought to be due in large measure to the erosion of the bank areas that support established vegetation. This erosion redistributes both mineral and organic nutrients that can be used by the primary plant types.

D. Successional Vegetation

The processes of aggradation and degradation described above occur on an annual basis as a result of spring breakup and summer rainstorms. These annual cyclical events cause a long-term trend characterized by a rich diversity in the species and patterns of vegetation in alluvial areas. The high productivity of wildlife habitat in these areas is a function of this diversity. There are also periodic unpredictable events such as exceptionally low or high water levels that also promote the existence of productive wildlife habitat.

Plant community types found in deltas include aquatic communities

Figure 3.7
Aquatic Vegetation
MacFarlane River

Figure 3.8
Emergent Vegetation in Mudflat

in open water (Figure 3.7), shore communities, emergents that grow on mudflats (Figure 3.8), meadow communities, shrub communities, and forest communities. Plant succession on various delta sites does not follow a single pathway but takes the form of a branching network. Several distinctly different species or species groups may dominate apparently identical sites during some specific successional stage, then give way to a single plant community at some succeeding stage. It is not clear why sites that appear to be physically and successionally identical are occupied by different species groups. The supply of plant seeds at the time when conditions happen to be favourable for germination is probably an important factor. In general, most delta areas have a vegetational sequence (Figure 3.9) that begins with aquatic and emergent communities, which are replaced by shoreline pioneers on exposed mudflats and then eventually become meadows. Meadows, in turn, are replaced by willow-shrub communities, which give way later to poplar and finally coniferous trees. The most mature communities are found on the highest and best defined levees (Figure 3.10).

Extensive, very flat sedge and grass meadows on the Peace-Athabasca and Mackenzie Deltas are periodically flooded by standing or

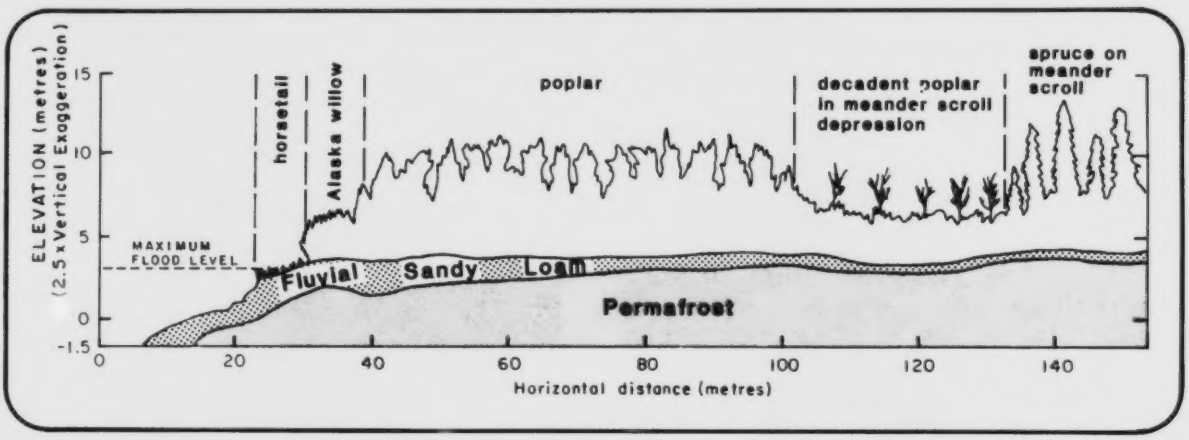


Figure 3.9
Vegetational Succession

Figure 3.10
Vegetational Succession
Mackenzie Delta

slowly moving water. The water table extends as high as the rooting zone for part of the growing season. Meadows, levees, and perched basins all receive some sediment when flooding occurs. However, the rate of deposition is relatively slow in locations distant from sediment sources. In inactive delta areas, lack of regular flooding results in gradual fixing of available nutrients in undecomposed organic material. Floating sedge mats grow over entire ponds which eventually fill with mud and peat and develop into bogs.

In active delta areas under natural conditions, succession to drier vegetation types may be slow. For example, it took more than 40 years for a sedge-dominated meadow on the Peace-Athabasca Delta to succeed to grasses and some willows. Even then, some of the change noted was probably a result of general drying of the delta after completion of the W.A.C. Bennett Dam.

Under most natural circumstances, succession on a delta is controlled primarily by water regime. If there is a normally fluctuating hydrologic cycle, sites directly influenced by fluctuating water levels tend to be maintained at early successional stages until such processes as channel shifting or levee building drastically alter the local water regime. However, if water levels decrease, replacement of one plant community by another proceeds rapidly in the early successional stages, then more slowly in shrub and forested communities.

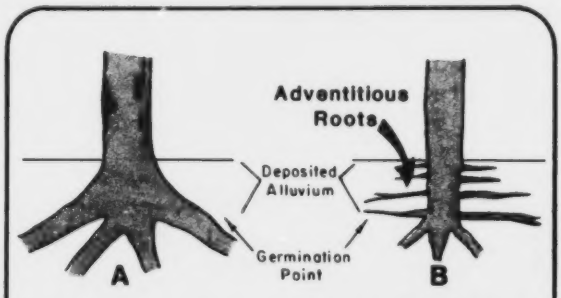
Successional zones of distinctively different vegetation types are so prominent on non-deltaic alluvial sites that there are now many textbook documentations of successional trends on floodplains, although there are not many such accounts from within the Mackenzie River Basin.

The general successional trends common to alluvial sites within the Mackenzie River Basin can be summarized as follows. As soon as the surface is exposed above average summer water levels, colonization by plants, usually horsetail, occurs. When further depositions of sediment raise the surface sufficiently, willow becomes established. The willow and horsetail zones are subject to the heaviest flooding and sediment deposition. When the alluvial surface is raised above the bankfull stage, alder, balsam poplar, and white spruce become established. As balsam poplar mature and die they are replaced by white spruce. Once they become established, willow and alder may remain as understory shrubs throughout subsequent stages. These successional trends are illustrated in Figures 3.9 and 3.10.

The vegetational sequences described above can be interrupted by continued river meandering or catastrophic floods and fires. Unlike adjacent upland areas, alluvial sites are seldom disturbed by fire. Consequently, white spruce trees of great ages are found on some alluvial sites. This relative absence of fire is due to barriers to the spread of fires presented by floodplains, river meanders, and oxbow lakes. The large amount of exposed mineral soil after flooding provides little surface fuel for fires, and there is little combustible surface material throughout the floodplain forest for a considerable time after each flood period. If the vegetational sequence is not interrupted, further succession to a black spruce and moss or black spruce and bog type of vegetation is possible.

E. Use of Alluvial Habitats by Plants and Animals

Areas subject to fluctuating water levels are dominated by plants that have special adaptations to meet such changing conditions. For example, perennial plant species that are able to survive in zones of intermittent flooding, such as willow, alder, balsam poplar, and white spruce, generally have root systems that respond to new deposits of sediment by production of adventitious roots on the buried portions of the stems (Figure 3.11). Other adaptations include production of additional underground stems by horsetail and rushes in flooded areas. The presence of annual or biennial life cycles that are timed to match the annual drawdown period in alluvial sites, such as on the Peace-Athabasca Delta, are additional adaptations that indicate vegetational occupancy of alluvial sites is not simply an extension of upland vegetation onto the naturally irrigated flood zones. There is, in many cases, a distinctive set of physiological responses that have evolved to aid survival of plant popula-



A. flared base suggests recent and heavy deposition

B. inverted cone-shaped base with adventitious roots suggests early and repeated deposition

Figure 3.11
Adventitious Roots

tions in the variable physical environment of floodprone areas.

Species of plants that are adapted to take advantage of the special conditions occurring in alluvial habitats are present at all levels in the vegetational sequence. Water horsetail invades and dominates the newest parts of levees and point bars in the Mackenzie Delta. As well as being able to establish itself in extremely wet soil, horsetail is able to grow from stems buried by alluvium. Once horsetail is established at a site, it moves rapidly into newly exposed alluvium by this method of propagation.

Plant species that colonize alluvial areas have a variable tolerance to flooding. Among emergents, the common great bulrush will die out in the second year of flooding if the water depth is greater than about 40 cm. Cattail and some sedges are reduced in abundance and vitality after three years of water depths exceeding 30 cm and will die out in the fourth year if such water levels are maintained. Well established willows are the woody plants most tolerant of flooding. They are eliminated only after three or four years of continuous inundation of at least 60 cm.

The vegetational sequences outlined in the previous section have direct relationships to patterns of wildlife use. Moose depend on early succession plant communities for food, particularly in winter. Alluvial plant communities along river channels and terraces and on minor deltas provide optimal winter habitat for moose. Alluvial areas provide a concentration of suitable food species for moose in association with nearby stands of conifers which are used as cover. Islands may be used by moose in the Mackenzie River Basin as winter sites and by females with calves in the spring.

The best sources of food and building material for beavers are usually found on older successional stages that support willow, balsam poplar, alder, birch, or aspen. In some locations, a shortage of food appears to limit the period of time a beaver colony can occupy a given location, while at other sites beaver seem to remain indefinitely. A more localized vegetational sequence, typical of point bars on the Mackenzie Delta, can create a distinct type of beaver habitat. As channels shift, differential flow around curves picks up sediment from the channel bed and deposits coarse alluvium on point bars. Meander scroll depressions which impound local runoff are formed at the same time as point bars. Balsam poplar, a preferred food species for beaver, colonizes the coarse point bar deposits. Food attracts beaver to the site, and damming of nearby meander scroll depressions meet their other requirements.

Superimposed on the distinctive ecological processes within alluvial sites are certain specialized features of resident species. Some animals that inhabit alluvial ecosystems are particularly well adapted to take advantage of opportunities offered by a rapidly changing environment or to avoid some negative consequences of it. Waterfowl are among the flexible species. Birds that would normally nest on the prairies can bypass them in years of drought and spend the summer on northern deltas. In many areas, renesting is possible if the first nest is destroyed, by early summer flooding for example. Other examples of wildlife adaptations centre around reproductive potential once favourable conditions are created by flooding and drawdown. Muskrats are prolific and can colonize newly created habitats soon after they become available. A single female will raise two or three litters each summer and populations have risen as much as 500% over a three-year period. Among ungulates, moose are particularly well able to

respond to changes in quantity or quality of available habitat because of their relatively high reproductive potential. If range conditions are good, a high proportion of yearlings may breed and older females commonly produce twins.

In some situations, animals can influence vegetational succession as well as being influenced by it. Selective removal of poplar by beaver on point bars alters the flora to cause secondary succession. If the site is occupied by beaver long enough, alder and willow become dominant. When beaver abandon such point bars, poplar begin to regenerate. After several years the site may again be attractive to beaver.

Another example of wildlife influences on alluvial vegetation occurs in certain delta lakes that are connected to larger channels by a single small stream which normally drains the lake. Under flood conditions such streams reverse their flow and carry silt-laden floodwater into the lakes. Where the inflowing current meets the water of the lake, silt is deposited in a small delta that projects into the lake, and forms a reverse delta (Figure 3.12). The newest portions of reverse deltas are covered with grasses. Such sites are the only locations in the Mackenzie Delta that support the grass, Beckmannia syzigachne. Seeds of Beckmannia are eagerly eaten by ducks, and the plant is thought to be maintained by seeds carried from the south by migrating waterfowl. A second grass species, Arctophila fulva, is particularly common on reverse deltas although it also occurs elsewhere. The vigour of Arctophila is thought to be encouraged by repeated cropping by waterfowl and nutrient additions from droppings which are high in nitrogen.

Migratory birds, other than waterfowl, have not been studied in detail in the Mackenzie River Basin.

Figure 3.12
Reverse Deltas
Mackenzie Delta

Deciduous plant communities apparently support a greater diversity of birds than do plant communities that are predominantly spruce. Because alluvial ecosystems support several plant communities and often exhibit many ecotones, they probably host the greatest variety of terrestrial bird species.

Non-migratory game birds that use alluvial areas along rivers include grouse and ptarmigan. Ruffed grouse are common on alluvial terraces in deciduous and mixed forests in southern parts of the basin. In northern parts of the basin, willow ptarmigan are common. In winter, flocks of several hundred ptarmigan may move into alluvial sites along aggrading banks. Their requirement seems to be willows with buds protruding above the snow for food, taller willows for shelter, and soft snow for burrowing.

Northern deltas are most important to continental waterfowl populations in years when drought strikes the prairies. Then thousands of birds bypass their intended prairie destinations and spend the summer on deltas within the basin. The northern deltas may also be of increasing importance for waterfowl production because as prairie pothole lakes disappear, a greater proportion of the annual continental waterfowl production may be coming from the north.

The importance of riverbank alluvial areas to wildlife could be assessed more objectively if comparative data were available on primary and secondary productivity in alluvial and non-alluvial areas. It is commonly assumed that there is high productivity on alluvial areas, with more animal and bird growth in response to the higher plant productivity in these areas. There is not only faster growth of individual plants, but there are more plants as well, especially those in the early successional stages. It is also thought that the plant species used by wildlife in alluvial areas have higher nutrient values than plants used by wildlife in upland areas.

The reasons for choice of certain plant species as food for wildlife may be nutrient content, but a variety of other factors may also be involved, including: succulence or palatability, growth form, height of shrubs, season of use, water depth in relation to growth forms, or type and abundance of associated plants. Available data show no clear correlation between choice of food species by animals and nutrient value of plant taken. Nutrient requirements of northern animals are not known in detail.

Alluvial areas in the basin are important to some populations of nearly all species at some time of the year. The possible exceptions are barren-ground and woodland caribou. Even marten, traditionally considered a species restricted to pure conifer stands, occupy upland river valleys where there is an abundance of prey.

F. Effects of Alluvial Vegetation on Fluvial Processes

It is common to think of relationships between physical and ecological processes as though they consisted entirely of effects of the physical environment on biological components. However, the vegetation on alluvial sites significantly influences the effect of some physical processes.

Vegetation along stream channels can influence the reaction time associated with variations in discharges of water and sediment. In the absence of major floods, vegetation continually encroaches on the stream channel, increasing bank resistance and reducing the rate of change of bank position (Figure 3.13). Effects such as these would be negligible in major rivers in the basin. In small tributaries, however, well-vegetated channels tend to be narrower than those without vegetation. If a channel loses its fringe of vegetation cover, the unprotected channel will tend to become wider than the original. When trees are removed by major floods they may float downstream and become part of the debris responsible for jams, floods, and channel diversions.

Unvegetated faces of point bars, particularly in the Mackenzie Delta, are subject to wind erosion. During winter, wind prevents snow from accumulating on many point bars. Such snow-free surfaces are subject to erosion by wind and abrasion by wind-driven snow. Most of the sand removed from the point bar is deposited just within the leading edge of vegetation where wind speed is reduced. As the point bar builds, willow and poplar

Figure 3.13
Vegetation along Stream Channel

move outward and are followed by other successive bands of vegetation. These phenomena encourage the continuing development of the point bar, which in turn has its effect on the changing course of the river channel.

G. Evaluation and Conclusions

Comparisons of ecological processes at alluvial sites in the Mackenzie River Basin with those in floodplains and deltas elsewhere suggest that many of the principles are of widespread application to floodprone ecosystems. Flooding and drawdown appear to be the key external forces that determine vegetational composition and productivity on floodplains. However, flooding can either enhance or stress an alluvial ecosystem depending on the frequency, timing, and intensity. Over the annual cycle, the beneficial effects of flooding seem to exceed its negative results in natural floodplains where organisms are well adapted to the flooding regime. Extremes of stagnant water or abrasive flooding stress the biotic community and reduce productivity. In contrast, seasonal flooding of natural floodplains in natural watersheds generally increases productivity in comparison with adjacent uplands.

Evidence from a broad range of ecological studies indicates that for animal populations, both the density and diversity of species tend to be higher at places where water and land meet than in adjacent uplands. Not only are many small species restricted to alluvial habitats, but many large animals require access to stream or lake margins to survive, even though they may spend much of their time elsewhere. Whether the places where water and land meet are taken to mean entire floodplains or only channel margins, there is evidence that flood-prone areas possess several characteristics that make them stand out as areas of special significance.

Several different hydrologic processes control the formation and destruction of alluvial ecosystems, but in the Mackenzie Basin the spring breakup period is the dominant event. Directly and indirectly, the spring breakup is responsible for continued primary production of plants and the diversity of plant species on alluvial sites. This in turn supports high animal productivity. In addition, the combinations of plant and animal species that occur on alluvial sites are often distinctly different from those on nearby non-alluvial areas.

The Peace-Athabasca, Slave, and Mackenzie Deltas are the largest concentrations of wetlands in the basin (Figure 3.14). Their large areas and many lakes contrast with the linear alluvial areas in river valleys and

provide preferred habitats for vegetation and wildlife.

Although alluvial sites make up a small percentage of the total area within the Mackenzie River Basin, studies of forest and agricultural potential within the basin have confirmed

1 Mouth of Mackenzie River at Kittigazuit Bay
2 Tuktoyaktuk
3 Kugmallit Bay
4 Mackenzie Bay
5 Kendall Island Migratory Bird Sanctuary

Figure 3.14
Mackenzie Delta

other findings that alluvial sites are the most productive sites in any given region. Along several tributaries of the Mackenzie River, the most productive regional forest areas are those that develop on recent alluvium or on river terraces.

The distinct plant and animal communities of alluvial sites, and their relatively high productivities, are the end result of a complex web of climatic, fluvial, and biological processes that interact to form areas of special significance along river channels and on the deltas of the Mackenzie River Basin. The processes involved in these intricate relationships are a result of depositional and erosional forces, vegetational responses to these fluvial processes, vegetational controls over wildlife use of alluvial sites, and a variety of ecological and physiological adaptations that allow resident plant and animal species to use the dynamic habitats of floodprone areas effectively.

Thus, providing the spring breakup and other floods continue, alluvial ecosystems represent regularly disturbed or disclimax communities of plants and animals. Furthermore, drainage patterns of alluvial systems ensure a good distribution of alluvial sites throughout the entire Mackenzie River Basin. Consequently, plant and animal species from alluvial sites are available to colonize suitable locations nearby when disturbances, such as fire, make them available.

The alluvial ecosystems study provided a general understanding of the forces and processes that physically shape northern floodplains and other alluvial areas and account for their high productivity in terms of providing a rich variety of flora and fauna.

Information assembled to date has tended to focus on processes associated with long-term trends such as ecological succession and with the period following catastrophic or unusual events such as high floodwaters. However, some of the less dramatic events that occur each year, such as drawdown, are not well documented yet in relation to the life cycles and vitality of plants and animals that inhabit areas subject to annual drawdown.

The study identified some aspects of alluvial ecosystems about which little is currently known. There is not enough information to allow meaningful comparisons between alluvial and non-alluvial sites. There have been no standardized measurements that would yield comparative data in terms of biological productivity, nutrient content of vegetation eaten by wildlife, and relative uses of alluvial and non-alluvial areas for animals that seasonally move from one to the other. If such data could be obtained, they could be integrated with the many things already known about hydrologic processes in the basin. Such an integration would promote a better understanding of the relative importance of alluvial sites for people and animals living nearby.

The study results illustrate the dependency of existing species and patterns of plants and animals on naturally fluctuating river regimes within the basin. The study report does not describe specific alluvial areas and their relation to specific river regimes and fluvial areas. Such site-specific studies should be a part of any future environmental impact assessment of projects, which, if built, could alter natural river regime.

A. Spring Breakup in the Mackenzie River Basin

B. Liard River Studies

C. Mackenzie Delta Ice Studies

D. Potential Effects of Upstream Regulation

E. Evaluation

Spring Breakup

4

The preceding chapter deals with the process of breakup and its importance to the alluvial ecosystem. This chapter deals with the Liard River which normally triggers the breakup process on the Mackenzie River and continues to influence breakup downstream, as far as the Mackenzie Delta and the Beaufort Sea. The Liard River plays this important role for four reasons:

1. The Liard has a large spring runoff, which peaks very quickly because of its headwaters high in the mountains, steep terrain and river profile, and the absence of lakes for natural storage.

2. The large flow of warm Liard River water breaks up and melts the Mackenzie River ice much earlier than would occur without the action of the Liard River water.

3. The Liard River contributes more suspended sediments to the lower Mackenzie River and the Mackenzie Delta than any other Mackenzie tributary.

4. The large spring flows from the tributaries above Great Slave Lake do not contribute to the early breakup of the Mackenzie River because the large storage capacity of that lake regulates the outflow.

The discussion begins with a description of the spring breakup in the Mackenzie River Basin and some of its important characteristics, then turns to the results of ice breakup and suspended sediment studies undertaken in the Liard River Subbasin. A description of the Mackenzie Delta ice study and an examination of the implications of upstream regulation of the Liard River follow. The chapter concludes with an evaluation and a recommendation for further study. The study is described in detail in Supplement 3 to this report.

A. Spring Breakup in the Mackenzie River Basin

Spring breakup starts in April in the southern tributaries of the Mackenzie River Basin, generally works its way northward, and is completed in about six weeks. The last large channel in the Mackenzie Delta to clear of ice during the 1980 breakup was the East Channel of the Mackenzie River (June 17). Because of the large size of the basin, from latitude 54°N to 69°N, it is not surprising that breakup can still be in progress in the Mackenzie River Delta in June, when headwater streams such as the Peace and Athabasca are experiencing early summer rainstorms. Great Slave Lake remains ice covered long after the Mackenzie River ice has been broken up by the Liard River below Fort Simpson. Great Bear Lake is the last major lake in the basin to clear of ice and remains free of ice for only two months.

Liard River Breakup Stages

Breakup in the Liard River Subbasin occurs in three stages. First, the ice cover is weakened "in place" by increasing solar radiation. Later, as the river flow under the ice increases, the weakened ice is fractured, lifted up, and eventually moved downstream in pans and floes (Figure 4.1). However, since the ice cover still has considerable strength at the time of first ice movement, rapid mechanical breakup requires a continually increasing flow of water. In the third stage, the accessible stranded ice debris is flushed out by the rising water which follows breakup.

Figure 4.1
Ice Pans and Floes

For the purpose of this study, breakup is considered to be complete at any location when the bulk of the upstream ice is fractured and cleared from the channel, and backwater effects from downstream breakup events are no longer noticeable.

Mackenzie River Breakup Stages

The Liard River is the major determinant of the Mackenzie River's breakup. It is the first major river to break up below Great Slave Lake and suddenly delivers large volumes of water to the Mackenzie River, usually when that river is still completely ice covered. At the beginning of May, for example, the Liard River contributes only 20% of the Mackenzie River flow at Fort Simpson, but this percentage can rise to 70% in early June when the Liard River is usually in peak flow. In the months of May and June the Liard River roughly doubles the flow of the Mackenzie River (Figure 4.3). The large volume and high velocity of the Liard River water put tremendous pressure on the Mackenzie River ice cover. As the warm upstream water encounters solid ice, it

Figure 4.2
Liard River Suspended Sediment
entering Mackenzie River at Fort Simpson, May, 1980

transfers heat energy to the ice and weakens it rapidly. The turbidity of the Liard waters also increases the absorption of solar radiation by the Mackenzie River ice, and thus hastens breakup further (Figure 4.2).

In the meantime, as the ice clears out of the Liard River and other upper basin tributaries, the water temperature increases dramatically. The southern waters continue to be warmed rapidly by the sun. Generally the farther downstream they encounter an ice cover, the warmer the ice-free water immediately upstream of the ice front will be. This dramatic difference in temperature was observed at Fort Good Hope during 1980. The water temperature of the Mackenzie River rose 8.5C° in a 13-hour period as the river ice was cleared past Fort Good Hope.

B. Liard River Studies

1. Ice Breakup

The process of breakup just described is subject to several factors that can make each year's event different and unpredictable. The first is the amount of water resulting from snowmelt, which can be estimated from snow surveys that are carried out just before breakup. The second and most unpredictable factor is the timing and duration of snowmelt. Rapid snowmelt can cause large amounts of water to enter ice-covered streams in a short time. Ice thickness is a third factor. If the amounts of water are larger and the ice strength is great, large ice jams are likely to occur. The breaking of large ice jams releases even greater amounts of water, promoting rapid and often spectacular ice clearance farther downstream.

The powerful influence of the Liard River is demonstrated by the fact that the Mackenzie River above the confluence of the Liard River has uniform flows and experiences few and minor ice jams, whereas below the Liard confluence the Mackenzie River experiences a much greater range of flows and severe ice jams. The community of Fort Simpson has felt the effect of several floods caused by ice jams.

Finally, breakup also depends on the strength and thickness of the ice itself, which is affected by the freezeup in the fall and weather conditions during the winter. Unfortunately, this phase of the ice regime has received little study, perhaps because of the cost and time involved in observing freezeup until stable ice cover exists. A modest start in documenting fall freezeup was made in this study and should be part of the proposed continuation of breakup studies.

The main purpose of this study was to observe and describe the process of breakup of the Liard River and to document the effect of the Liard River flows on the Mackenzie River. Based on satellite imagery for the period 1973-77 that helped identify locations prone to ice jams, the study concentrated on selected reaches of the Liard, Fort Nelson, Muskwa, and Prophet Rivers. Breakup was documented by aerial photography and by ground observations at specific sites before, during, and after breakup.

Liard Flows It had been hoped that the study could document a typical Liard River breakup, and perhaps even a spectacular one. Instead, the flow during April-May, for the three study years generally stayed below the average for the previous recorded years (Figure 4.4). This did not prevent an impressive ice shove from occurring at the Town of Fort Simpson during a short period of above-average flow during 1978 (Figure 4.5). However, in 1980 the water levels were so low before breakup, and increased so little during breakup,

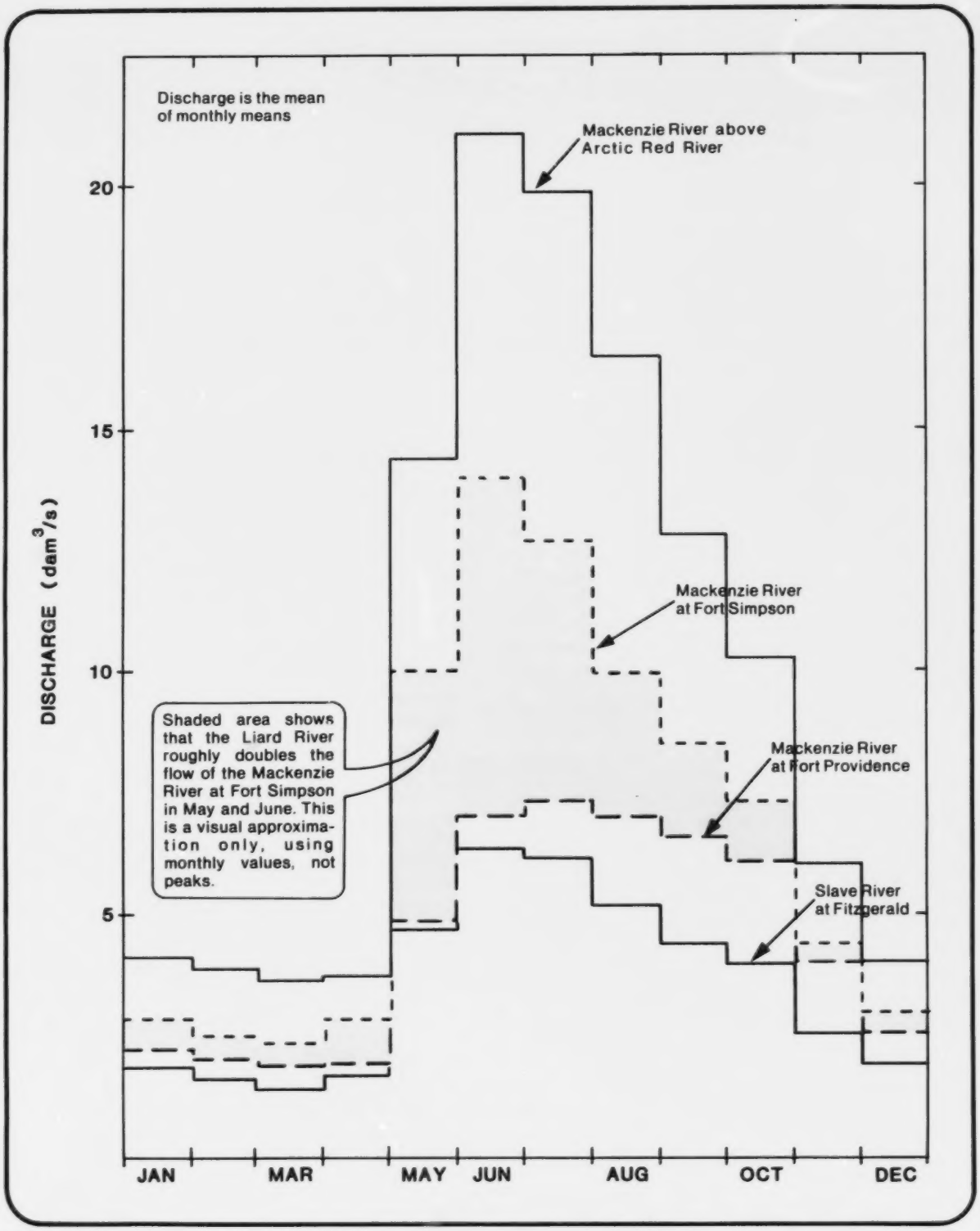

Discharge is the mean of monthly means
Mackenzie River above Arctic Red River
Mackenzie River at Fort Simpson
Mackenzie River at Fort Providence
Slave River at Fitzgerald
Shaded area shows that the Liard River roughly doubles the flow of the Mackenzie River at Fort Simpson in May and June. This is a visual approximation only, using monthly values, not peaks.
DISCHARGE (dam³/s)
20
15
10
5
JAN
MAR
MAY
JUN
AUG
OCT
DEC

Figure 4.3

Importance of Liard River Flows

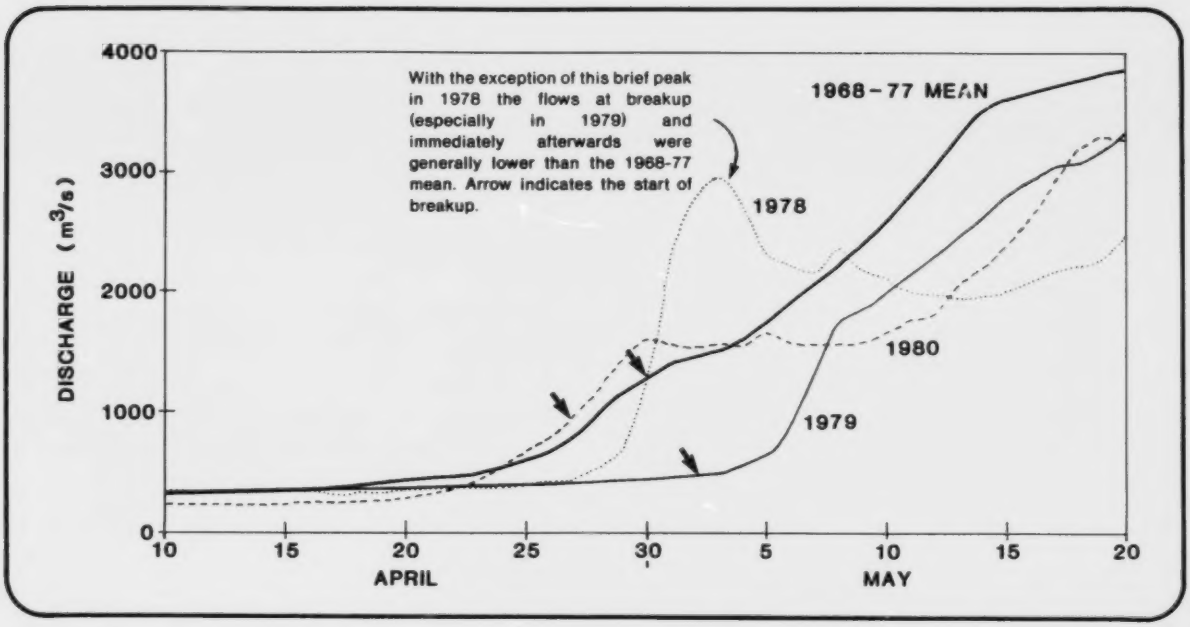


Figure 4.4
Liard River Daily Discharge
at Fort Liard, April to May, 1978-80

that the ice was not shoved onto exposed river banks except at several ice-jam locations.

Ice-Jam Locations The location and frequency of ice jams is determined by certain physical characteristics of the river channel (Figure 4.6). Ice jams in the Fort Nelson River were located at sharp bends or in areas where shoals contained mid-channel sand bars, or where previous high flows had deposited masses of log debris.

On the Liard River, between Nelson Forks and Fort Liard, ice jams formed at channel restrictions that were imposed by divided channels and point bars. When flows are low during breakup, the ice grounds on shoals in the channel. Similar shoal island areas are responsible for jams in the reach below the Liard-Muskeg confluence to Flett Rapids.

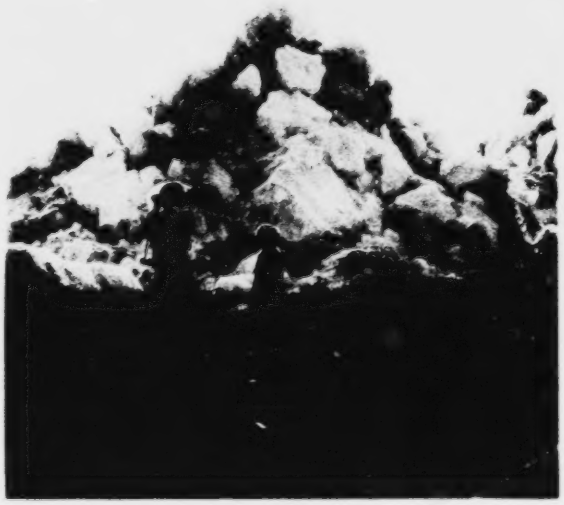


Figure 4.5
Ice Shove
Fort Simpson, N.W.T.

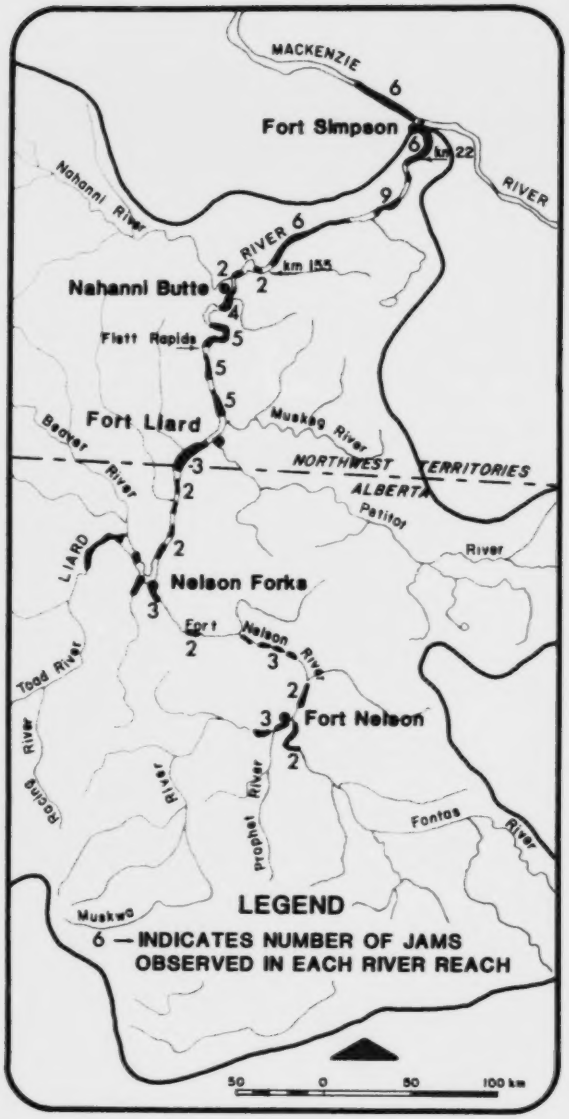


Figure 4.6

Ice Jams

Location and frequency, 1973-80

Between Flett Rapids and the junction of the South Nahanni, a series of river bends retain the ice cover or cause jamming. In 1979 and 1980 ice in this reach remained in place after the breakup front progressed a considerable distance (50 km) downstream.

In the winters when Flett Rapids remain open, ice crystals are formed by the water coming into contact with the cold air, but they are prevented from joining each other by the turbulent water. This frazil ice is eventually swept under the existing ice cover farther downstream and may be transported 10 to 20 km downstream to a curved reach. Here it may attach itself to the underside of the ice cover, causing ice to become thicker than normal. This may explain why the ice in this curved reach remains intact after ice located downstream of this reach has broken.

Relatively few ice jams were observed in the Liard River immediately downstream of the junction with the South Nahanni River. In 1979 and 1980, the South Nahanni River broke up without affecting the Liard ice at its confluence. This suggests that during years when flows are below long-term averages, the South Nahanni may not be a major influence in the breakup of the lower Liard River.

Between km 155 and the island upstream of the Liard River ferry crossing at km 22, ice jams have been frequent but are of little importance to sediment production or flooding (Figure 4.7). The channel is essentially straight over much of the distance, while the banks are steep and fairly cohesive, with some bedrock outcrops. Aerial observations indicate that only 5% of the banks in this reach are undergoing active erosion, and that ice action is responsible for little of it.

Major jams occur every year from km 20 (just below the ferry crossing) almost to the mouth of the Liard River. The reasons for these jams are the existence of extensive shoal areas and islands in the channel near the mouth, which divide the flow and restrain the ice cover mechanically, and the hard intact ice cover on

Figure 4.7
Ice Shove
Liard River ferry crossing

the Mackenzie River, which stops the Liard River ice. The former reason predominates in low-flow years and the latter in high-flow years, but together they ensure that ice jams occur in this final reach of the Liard River every year.

Fort Simpson Flooding

Ice jams in the Mackenzie River below Fort Simpson have threatened the town on several occasions in the past. It has been thought locally that a large "rock" or bedrock outcrop in mid-channel just downstream of Fort Simpson is responsible for jam formation, and suggestions have been made to eliminate this obstruction by blasting. However, channel bore holes drilled during an engineering study for the installation of a new water supply intake pipe at Fort Simpson found clay as the most resistant channel bed material.

Although this study was not designed to examine the flooding problem at Fort Simpson, analysis of aerial photography shows that ice jams are caused by a left-bank shoal immediately below the island on which Fort Simpson is located (Figure 4.8). This shoal is formed by huge quantities of river sediment; therefore, there is no economical way of preventing the ice jamming. The only completely effective solution to the flood problem is to relocate the townsite to higher ground above the floodplain. Lesser measures could include floodproofing and partial relocation. The Fort Simpson floodplain will also be mapped and studied under the Canada - Northwest Territories Flood Damage Reduction Program.

Ice Breakup Study Results

Because flows at breakup during the three study years were below normal or just equal to the average flow, the results are inadequate. Continued study of the Liard River is recommended to ensure that the breakup during high-flow years is documented as well. On the other hand, the results provide an essential record of a series of low to average flow years and increase the understanding of what happens when the Liard River is a less dominant, though still powerful, influence on the Mackenzie River. The observations made during the study can be stated as follows:

a. In years of average discharge, the Fort Nelson River triggers Liard ice breakup from Nelson Forks to the mouth.

b. Ice breakup of the Liard River normally triggers the Mackenzie River breakup.

c. During low-flow years, ice breakup is not a major cause of sediment production or of sediment transport; what sediment it does produce from the bed and banks of the existing channel is transported later by higher summer flows.

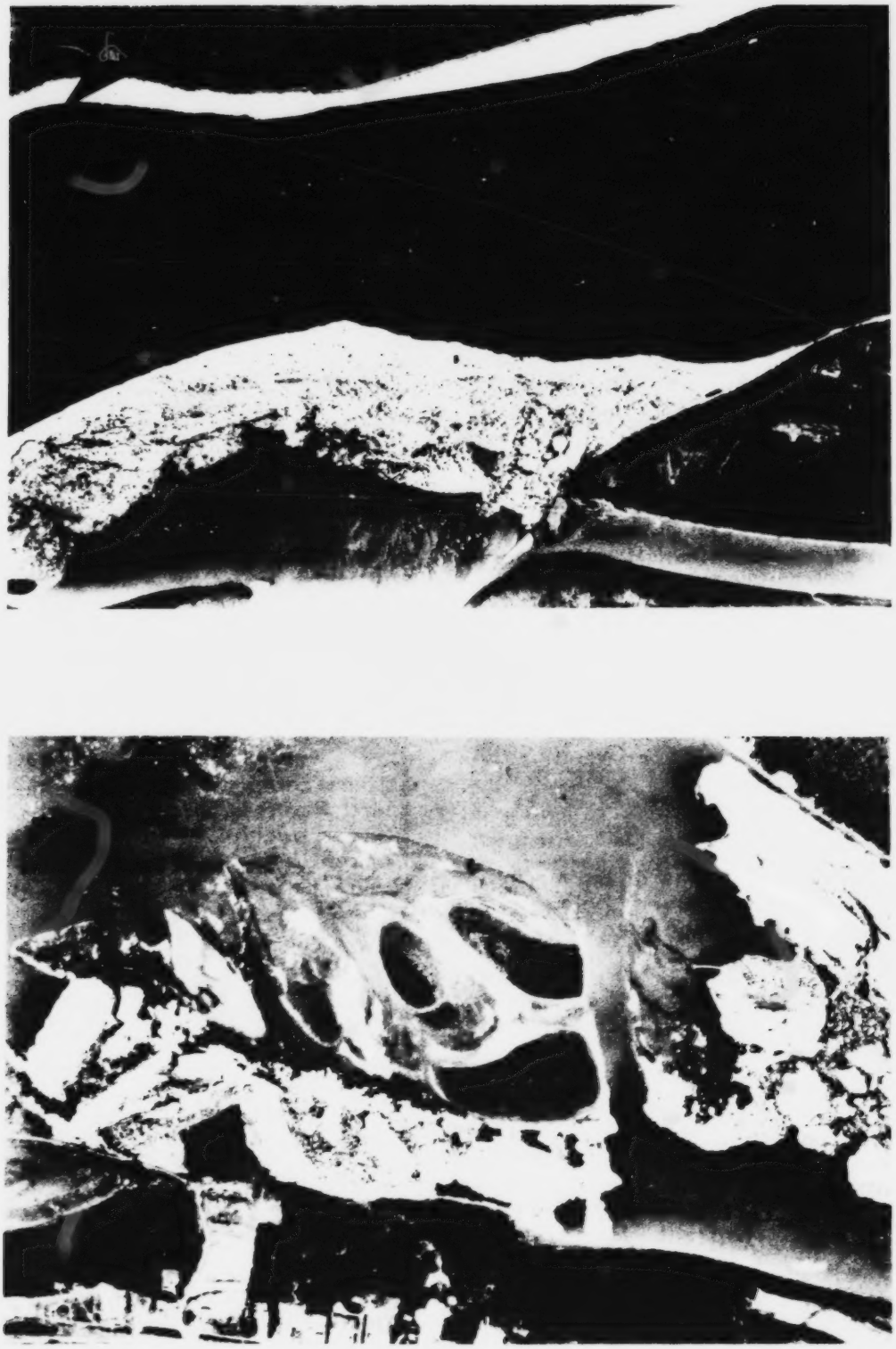


Figure 4.8

Ice on Shoal Areas
Liard and Mackenzie Rivers

d. When breakup is "premature," that is, when it is caused by large increases in flow while the ice is still thick and retains significant strength, sediment production increases. Large ice jams created under extreme conditions may have significantly higher than normal backwater levels, possibly higher than after summer storms, and may cause significant erosion from normally uneroded portions of the banks.

e. The characteristics and locations of ice-jam sites are predictable from aerial and ground observation over a period of years. For example, jam sites are usually at sharp bends, in narrowed channel reaches, and over shoal areas. Ice strength at breakup can have a significant effect on the formation and duration of an ice jam. A prediction cannot be made regarding when, or if, ice jams will occur in any particular year. Generally the frequency of ice jamming increases in low-flow years, but severity decreases. Too little is known about ice action during high flows, when major ice jams with the greatest potential for damage tend to occur. The Nelson Forks area in particular requires more study.

2. Suspended Sediment

It has been reported that more than 160 million tonnes of suspended sediment are delivered to the Mackenzie Delta in one year. As much as 24 million tonnes in one day were recorded for the Mackenzie River above Arctic Red River in 1974. A peak load of 10.8 million tonnes was calculated for the Liard River on July 21, 1974 alone. It is generally thought that breakup and the ensuing spring high flows are the most important periods for the production and transport of suspended sediment.

Regardless of the fact that these figures are based on short intermittent records, it is evident that the quantities involved are huge. Given the importance of sediments in river hydraulics and the alluvial ecosystem, the subject deserves close attention.

Nature of Suspended Sediment — Suspended sediment is eroded material suspended in, transported by, or deposited by water. In general, this limits the material to clay and silt sizes, and perhaps fine sand up to 0.25 mm in diameter. Erosion within a river basin is limited by either production or transport factors. Since most of the streams in the Liard River Subbasin are more than capable of transporting suspended sediment, variations in suspended sediment loads are more probably the result of production factors, such as degrees of weathering, corrasion and type of material.

Sources — Suspended sediment comes from two general sources: sheet wash and channel erosion. Sheet wash can be considered minimal in this subbasin since the heavy vegetation cover binds the soil and retards overland flow. Channel erosion includes a wide range of forms from tiny gullies to massive slumping. Among the factors contributing to channel erosion are the stage and velocity of the river, the presence of debris such as ice or logs, and the stability of the bank material. Bank stability is affected by cohesion, vegetative binding, and presence of ground ice and height of banks, especially if the presence of ground ice could lead to thermal slumping. External factors such as forest fires or vegetation stripping can also affect bank stability.

Channel erosion generally increases during the spring breakup period because the bank suffers the direct attack of moving blocks of ice. Ice jamming causes an elevation of river stage, and a water velocity increase when a jam bursts. The rapid drawdown of the water level after a jam

bursts can lead to slumping in unfrozen banks.

Sediment Production The flow immediately after the spring breakup on the Liard River is exceeded in many years by high summer flows. Since suspended sediment transport is closely related to river discharge, it follows that high sediment transport rates also occur in summer on the Liard River. However, several factors complicate the detailed analysis.

The first factor is the hydrologic variability of the Liard River Subbasin (Figure 4.9). Some of the Liard River tributaries may be in flood due to snowmelt from high elevations and some may have carried all their snowmelt water and have begun to recede, while others may be experiencing floods from summer rainstorms. The sediment contribution from a particular river to the total sediment load of the Liard River also changes throughout the season. For example, the Fort Nelson River contributes a significant percentage of the total sediment load during and shortly after breakup. As the flows of the Fort Nelson River recede after breakup, the Liard River above the Fort Nelson confluence assumes the role of major sediment transporter. The Fort Nelson River resumes its role as major sediment transporter during the summer storm period.

Secondly, it appears that vast quantities of suspendible material are loosened during breakup, but most

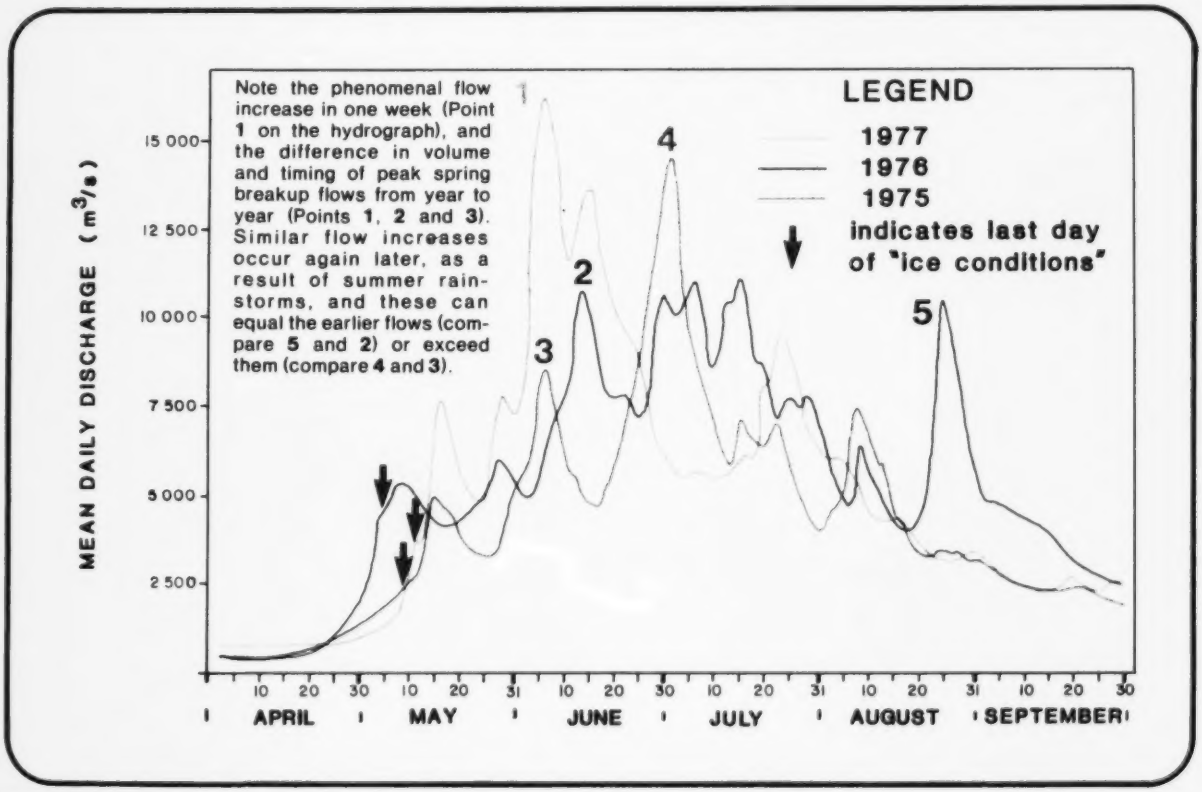

Note the phenomenal flow increase in one week (Point 1 on the hydrograph), and the difference in volume and timing of peak spring breakup flows from year to year (Points 1, 2 and 3). Similar flow increases occur again later, as a result of summer rainstorms, and these can equal the earlier flows (compare 5 and 2) or exceed them (compare 4 and 3).
LEGEND
1977
1976
1975
indicates last day of "ice conditions"
MEAN DAILY DISCHARGE (m³/s)
15 000
12 500
10 000
7 500
5 000
2 500
1
2
3
4
5
10 20 30 10 20 31 10 20 30 10 20 31 10 20 31 10 20 30
APRIL MAY JUNE JULY AUGUST SEPTEMBER

Figure 4.9
Liard River Flow Variability
near the mouth, 1975-77

of the material is not transported downstream until later by the high water velocities and levels associated with summer storms. Breakup is a good sediment production period because the water is held back by the river ice and ice jams, and often attains levels higher than those reached during the summer storm period. These high water levels allow the ice to scour the upper levels of the river banks, loosen the soil, and break it into transportable size (Figure 4.10).

Finally, there is a natural tendency for sediment to be carried only a short distance from its origin to a point bar or other location in the channel, since the velocities during breakup are high for only a short time after an ice jam fails. In this way it may take a long time for sediment to move downstream. It is even possible that the large quantities of material

Figure 4.10
Bank Scour
Liard River

Figure 4.11
Erosion and Deposition
Fort Nelson, Liard and Mackenzie Rivers

from severe bank erosion in the upper Liard require more than one open-water season to reach the mouth of the Liard River.

Suspended Sediment Studies — The reconnaissance work done in the spring of 1978 began with an analysis of topographic maps and sequential aerial photography for 1948 to 1975, to identify and map areas of erosion and deposition along the Mackenzie, Liard, and Lower Fort Nelson Rivers (Figure 4.11). Several sample reaches were selected for a detailed examination of changes in the spatial pattern of river banks, islands, and bars, again using the sequential aerial photography. The 1978 field work consisted of sampling all major streams in the Liard River Sub-basin accessible from the Alaska Highway.

The 1979 spring and summer field program concentrated on the Fort Nelson and Muskwa Rivers at Fort Nelson, B.C. Occasional samples were also taken at the Lower Crossing of the Liard River. The data indicated certain sediment concentrations in the Muskwa and Fort Nelson Rivers, which allowed estimates of daily sediment loads to be made. The miscellaneous sampling of the Liard River at the Lower Crossing and Nelson Forks suggested that the Liard River above the junction with the Fort Nelson River could also be an important source of suspended sediment during certain periods. Acordingly, a similar program was carried out in 1980, the last field study season.

Thermal Infrared Studies

The suspended sediment study was complicated by the remoteness and lack of road access in many parts of the Liard Subbasin, especially the 600 km long lower reach of the Liard River. Thermal infrared aerial photography was undertaken in an attempt to indicate sediment loads from the differences in water surface temperature between the Liard River and its major tributaries. This exercise proved unsuccessful in defining comparative sediment loads, but did document the relative turbidity of tributary streams, provide information on the mixing lengths of Liard and tributary waters, and illustrate the long mixing length of Liard and Mackenzie River waters.

Suspended Sediment Study Results

The shortness of the study period is the most important factor to be considered when reviewing the conclusions presented below. In reality, suspended sediment was measured over only two open-water seasons for a few selected sites within this large subbasin. During the 1979 and 1980 open-water seasons an attempt was made to sample all significant features of the hydrologic regime, and this proved to be fairly successful. Therefore, this study produced a fairly complete two-year record of suspended sediment transport in the Fort Nelson River system and miscellaneous data for the Liard River. The main results are listed below, followed by a brief discussion.

a. The area drained by the Fort Nelson and Muskwa Rivers is the most important for producing and transporting suspended sediment in the upper part of the Liard River Subbasin (above Nelson Forks). This conclusion is strengthened by the fact that sediment data from the Fort Nelson River correlates with the sediment data of the Liard River at the mouth more closely than the flow data of these stations. This suggests that although there are several other large tributaries between the Fort Nelson River and the mouth of the Liard, they contribute large volumes of water but little sediment.

b. Based on the sparse and sporadic record that is available, the Liard River Subbasin appears to be a major source of suspended sediment for the Mackenzie River over the open-water season. These results may underestimate the real situation since it was not possible to measure suspended sediment while the ice was running in the river.

c. The following conclusions regarding suspended sediment of the upper Liard can be made on the basis of the short record:

i. Suspended sediment is negligible during low winter flows.

ii. There is a surge of sediment transport as a result of breakup, even when (as in 1980) breakup water levels do not rise significantly over winter levels. The Fort Nelson River experienced the greatest surge in concentrations for both study years. This sediment increase can be due to sediment production as a result of ice damage, although very little was

observed in 1980. In addition, fine material can accumulate on the ice cover before breakup, due to late winter and early spring snowmelt. During the breakup period the Fort Nelson system is the main sediment contributor to the lower Liard River.

iii. Following breakup in the Fort Nelson system, the flow regime recedes to one of low flows, with occasional small peaks from summer rains, and the sediment regime is essentially quiescent during this period. In contrast, the upper Liard (as measured at Lower Crossing) usually experiences high flows and increases in concentration of suspended sediment from early to mid June. Although the concentrations of suspended sediment in the Liard at this time do not equal the spring values of the Fort Nelson system, the transported sediment load can be substantial as a result of the high flow regime. Accordingly, it is possible that for a short period in late May and early June the upper Liard is itself the main suspended sediment contributor to the lower Liard River.

iv. The influx of Pacific air masses into the upper Liard River Subbasin from mid to late summer usually causes a series of severe summer rainstorms. The intensity and frequency of these storms vary from year to year, but the streamflow records indicate that they produce the peak discharges for the year. This is especially evident from the records of the Fort Nelson and Muskwa Rivers. The data collected on these rivers show that the Muskwa River transported 80% of its seasonal load during 20 days of the summer storm period, and the Fort Nelson River transported 50% during the same period.

The high water levels and velocities associated with the summer storms erode the upper portions of the river banks. The erosive power of summer storms can be visualized from Figure 3.1 which shows a new channel of the Muskwa River created by a single summer rainstorm in 1977.

River banks that are above the areas eroded by high flows from summer storms are affected only by severe ice jams. Ice jams can raise the water levels several metres higher than peak flows from summer storms. It is only during this period of extreme water levels that the upper banks can be eroded by water and gouged by floating ice. The sudden drop in water level when an ice jam breaks can cause massive slumping of the saturated banks.

It would be premature to dismiss the importance of sediment transport during the breakup period just because most of the sediment in the upper Liard River Subbasin is transported later during the summer. The turbidity caused by sediment transport during breakup aids in the destruction of ice cover by lowering the albedo of the ice cover.

The results of the thermal infrared imagery study show that most

Table 4.1

Infrared Temperatures

Maximum infrared temperatures in mainstream and tributaries above surveyed confluences, 1978

LIARD RIVER			
	9.5°C	◁	[illegible]
[illegible]	9.5	▷	[illegible]
	9.5	[illegible]	FT. NELSON
	10.0	[illegible]	PETITOT
[illegible]	10.0		
MACKENZIE RIVER			
	4	[illegible]	LIARD
	4[2]	[illegible]	NAHANNI

Note Temperatures indicated are ±0.5°C (one half the imagery step size) except where noted.

1 Temperature indicated is ±0.8°C

2 Temperatures indicated are ±1.1°C

of the tributaries are warmer than the river they flow into, except the Muskwa, South Nahanni, and Beaver Rivers which are colder than the rivers they flow into (Table 4.1). They are colder because they receive water from the snow melting at high elevations. The tributary waters mix with the main streams in relatively short distances (6 to 11 km), with the exception of the Liard and Mackenzie waters which do not completely mix for some 100 km downstream of their confluence.

C. Mackenzie Delta Ice Studies

Upstream changes in river flow are most likely to influence the ecology of the Mackenzie Delta by the way they change freezeup, breakup, flooding, and sedimentation in the delta. It is, therefore, essential to understand the ice regime under natural conditions. A more immediate reason for being concerned is that ice roads provide the longest annual period of reliable travel in the Mackenzie Delta. Changes in the ice regime could interfere with transportation.

A review of the literature revealed that there has been very little study regarding the ice regime or freezeup and breakup processes in the Mackenzie Delta. Therefore, a small field program was started in spring 1980 to obtain one season's observations and establish the importance of warm spring floodwaters and how they affect the progress of breakup in the delta. Additional work should be undertaken over several complete seasons.

River Ice Breakup — Breakup of the Mackenzie River from Fort Norman downstream was uneventful in 1980, with no flooding or major ice jams. The ice front moved no more than 20 km daily, and breakup seemed to be caused mainly by subsurface melting. This reach was observed because ice conditions above the delta affect the delta directly.

Delta Ice Thickness — Measurements were made from April 15 to 25, 1980 when ice thickness was expected to be greatest. Ice thickness varied from 0.69 m in a channel carrying Peel River water to the main channel of the Mackenzie River, to 1.85 m on the East Channel near Kittigazuit Bay. Thicker snow cover and higher water velocities in deeper channels resulted in thinner ice. The three transects used for the test holes were later used for repetitive coverage by aerial photography during breakup.

Delta Ice Breakup — Monitoring from the air and on the ground extended from May 25 to June 16, 1980. The delta flooded extensively, around 65% in the southwestern (upper) part and almost 100% in the outer delta. Flooding of the delta lakes began in the outer delta near Shallow Bay and progressed upstream as breakup advanced and water levels rose. The East Channel between Reindeer Depot and Kittigazuit Bay was the last major channel section to clear of ice on June 15.

Water temperature measurements along a 20 km reach of the Mackenzie River show how quickly warm upstream water loses heat energy when it encounters ice and melts it. The continuous supply of warm water from upstream ensures that the ice continues to melt (Figure 4.12). The temperature measurements allowed a rough estimate to be made of the heat transfer between the warm upstream water and the ice front. The approximate volume of 10 000 m^3 of discharge at the recorded temperature could melt 100 million cubic metres of ice daily. Assuming a one metre ice thickness and a one kilo-

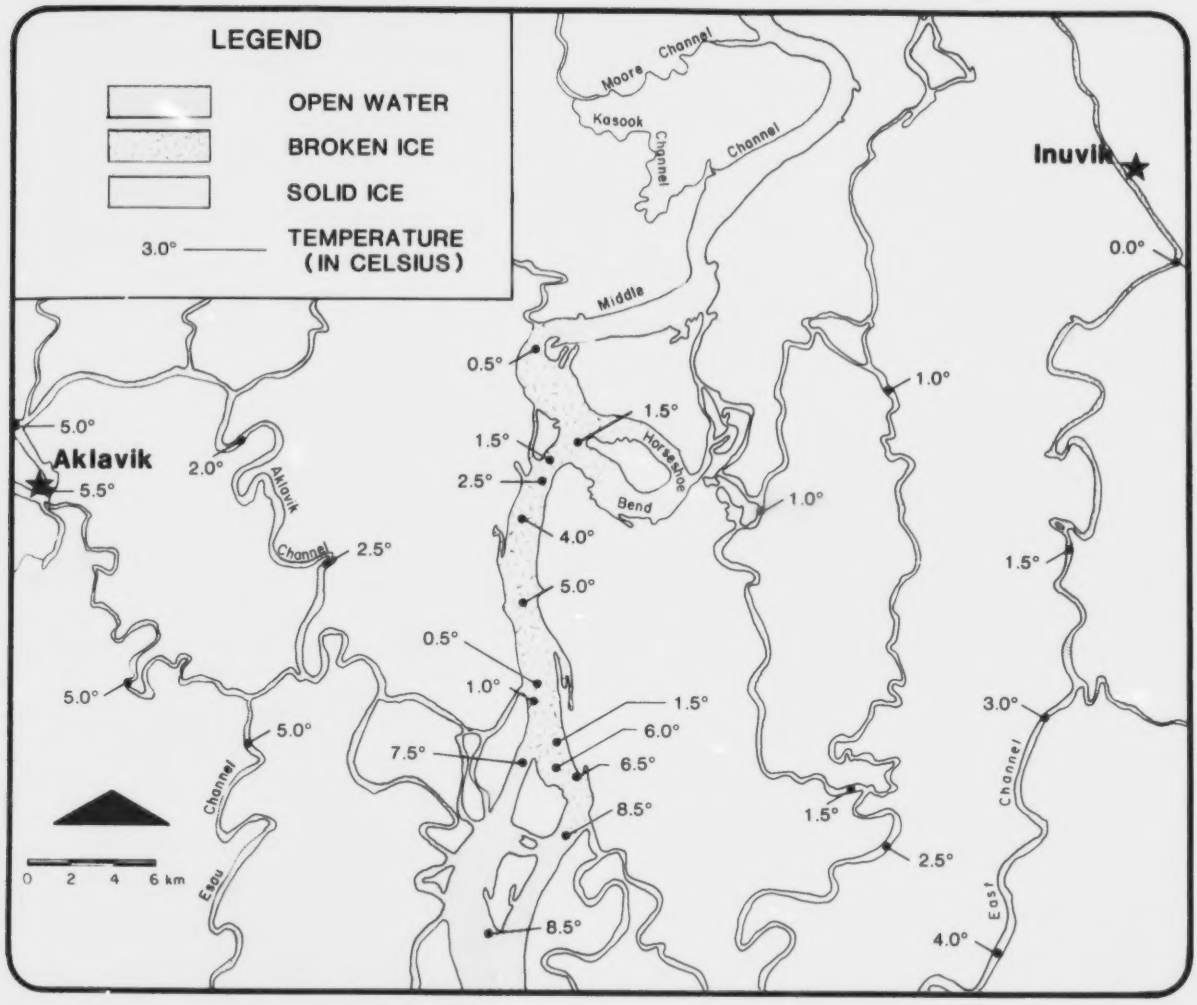


Figure 4.12

Water Temperatures at Breakup

Mackenzie Delta — June 1, 1980

metre channel width, this volume represents a downstream ice disintegration rate of 100 km a day. It must be emphasized that this figure will vary with channel width, ice thickness, water temperature, and discharge. Due to the relatively low discharge encountered in 1980, this thermal transfer of energy was an important element in the Mackenzie breakup.

In a separate assessment it was shown that the Mackenzie River contributes one third of the total energy input to the delta during breakup. Later the radiational and atmospheric energy sources supply almost all the heat energy to the delta.

Other factors that can affect delta breakup but were not included in the reconnaissance study are: flood peaks of rivers originating in the Richardson Mountains, local climatic effects of the Richardson Mountains on

the western part of the delta during freezeup and breakup, variations in ice thickness between channels, and the effect channel orientation has on snow accumulation.

D. Potential Effects of Upstream Regulation

Several preliminary assessments of the hydroelectric potential of the Liard River over the past 20 years have established the large hydroelectric power potential of this river. Current studies by the British Columbia Hydro and Power Authority are far more detailed and comprehensive than any previous studies and extend as far north as the Mackenzie Delta. The earliest project completion date, if the decision were made to proceed, would be in the mid-1990's. The Mackenzie River Basin Committee's study of the Liard River system is therefore very timely. It bears repeating here that the Committee has two purposes in improving the understanding of the basin's water resources: the first and most important reason is to improve the basis on which project decisions are made; the second is to ensure that the information is available for fair and comprehensive evaluations of such development proposals before they proceed.

Ice Jams The hydro power scheme envisaged by the B.C. Hydro and Power Authority would have two dams: one about 15 km below the Lower Liard Crossing called the Devil's Gorge Project (Site E), and the other located about 5 km above the confluence of the Liard and Beaver Rivers called the Beavercrow Project (Site A). It is the storage and release of water from this lower dam that will affect the breakup of the lower portion of the Liard River and also the formation of ice jams during breakup.

The release of water for power production in the winter months will increase the flow of the Liard River downstream of the dam to greater than normal winter values. This increase in winter flows may delay freezeup and result in ice forming at higher bank levels. This will result in a greater surface area of ice, since the width of rivers increases with an increase in water level in the stream.

Frazil ice may be formed in the open water immediately below the dam and carried under the downstream ice cover, making it thicker than normal. Thicker ice at higher bank elevations requires greater flow volumes during breakup to fracture it and float it downstream. The ice is more likely to form jams under high flows, and in low flows will take much longer to break up. While a jam here would present little or no danger downstream, breakup may be delayed and significant channel geometry changes can be expected in the area of the jam.

It must be remembered that spring breakup is not a simple hydrologic event. The timing and magnitude of spring breakup and its related phenomena are as much controlled by the preceding fall and winter precipitation and temperatures and weather conditions existing before breakup, as by the actual events due to water flowing through the channel. Consequently, the mathematical modelling of ice-jam events is extremely difficult and the results are of limited usefulness on a large river system such as the Liard. Furthermore, only after breakup under high flow conditions has been monitored can the Liard breakup be fully understood.

Suspended Sediments It is difficult to project the exact effects of water storage and regulation on the suspended sediment regime of the lower Liard River. Since no dams are envisaged on the Liard River below the

confluence of the Fort Nelson River, there will be no barrier to the transport of sediment from that river.

However, sediment from the Liard River above Nelson Forks, an important source from mid-May to mid-June, would become impounded. This has special implications for the life expectancy of the two reservoirs, apart from removing a significant portion of the suspended sediment load from the Liard River system. The question also remains where and how the river will replace this load farther downstream, and how this will affect the behaviour of the river over the years.

E. Evaluation

The annual spring breakup in the Mackenzie River Basin is a major and extremely variable event which cannot be evaluated on the basis of three years of field data. However, the study program did provide sufficient information to describe the processes involved in the breakup of the Liard River when river flows are below the long-term average. The study also provided some indication of ice breakup in the Mackenzie River Delta.

Sediment sampling provided valuable information on the major sources of sediment in the Liard River Subbasin. It also documented the changing sources of sediment from breakup to the summer storm period. The Fort Nelson River is a major source of sediment, in both the breakup and summer storm period.

The results confirm the rapid rise in water temperature of the Liard River and its tributaries after the breakup progresses downstream. These warm waters are important in the destruction of ice farther down the Mackenzie River to the Mackenzie Delta.

The study results were obtained during a period of below-average flows in the Liard River Subbasin. The monitoring and analysis of the spring breakup should be continued until several high-flow years have been documented. The monitoring program should also be expanded to include the Mackenzie River from Fort Simpson to its mouth.

A. Water Data Types
B. Network Concept
C. Network Analysis
D. Component Networks
E. Integrated Network Design
F. Evaluation and Conclusions

Water Data Needs

5

The importance of the water resource to the plants, animals, people, and economy of the basin is documented earlier in the report. Competition is growing for the use of this resource. The controversies accompanying nearly every major water resource project illustrate the resulting complexity of future management decisions. The question is not **whether** more water information is needed in the future, but **how much** and **what type** is required for effective water resource management.

This chapter summarizes the study and development of an integrated network design for water quantity, snow, meteorologic, sediment, and water quality data in the basin. The study is described in full in Supplement 4 to this study report, and background reports are contained in Supplement 5.

A. Water Data Types

The most urgent requirement is for reliable and representative pre-development data, against which future changes in the basin's water regime and environment can be evaluated. Water data now being collected tell only part of this story, and must be supplemented with carefully specified additional data. Obtaining a sufficient "period of record" before a project proceeds is often a race against time. The objective of this study component, therefore, is to develop an integrated network of measuring stations, which will provide the data for a coherent and comprehensive picture of the water quantity, meteorology, water quality, and sediment transport in the basin (Figure 5.1).

The primary and often only consideration in the past was the quantity of water available, as well as such related data as river level, water depth, and lake level. Since runoff depends on how much water is available in the first place, meteorological information on precipitation and weather conditions in general is important also. Measurements expressly designed to indicate the amount of accumulated snow are particularly important in this basin, as snowmelt from the mountains provides a very high proportion of the runoff. In contrast, low precipitation prevails in the entire eastern half of the basin.

The qualitative aspects of water have been monitored in the basin for little more than a decade. Water quality and suspended sediment reflect the various influences of geology, flora and fauna, and man's activities. This adds interpretive difficulties to the inherent technical difficulty and cost of obtaining and analyzing these data. Consequently, existing water quality and sediment networks have fewer stations than the hydrometric and meteorologic networks in the basin, in addition to having a very much shorter period of record.

B. Network Concept

The history of most data networks indicates that they developed primarily in response to specific uses and users. The number and location of stations; the frequency, detail, and required accuracy of measurements; and the limited effort made to analyze the results reflect this situation.

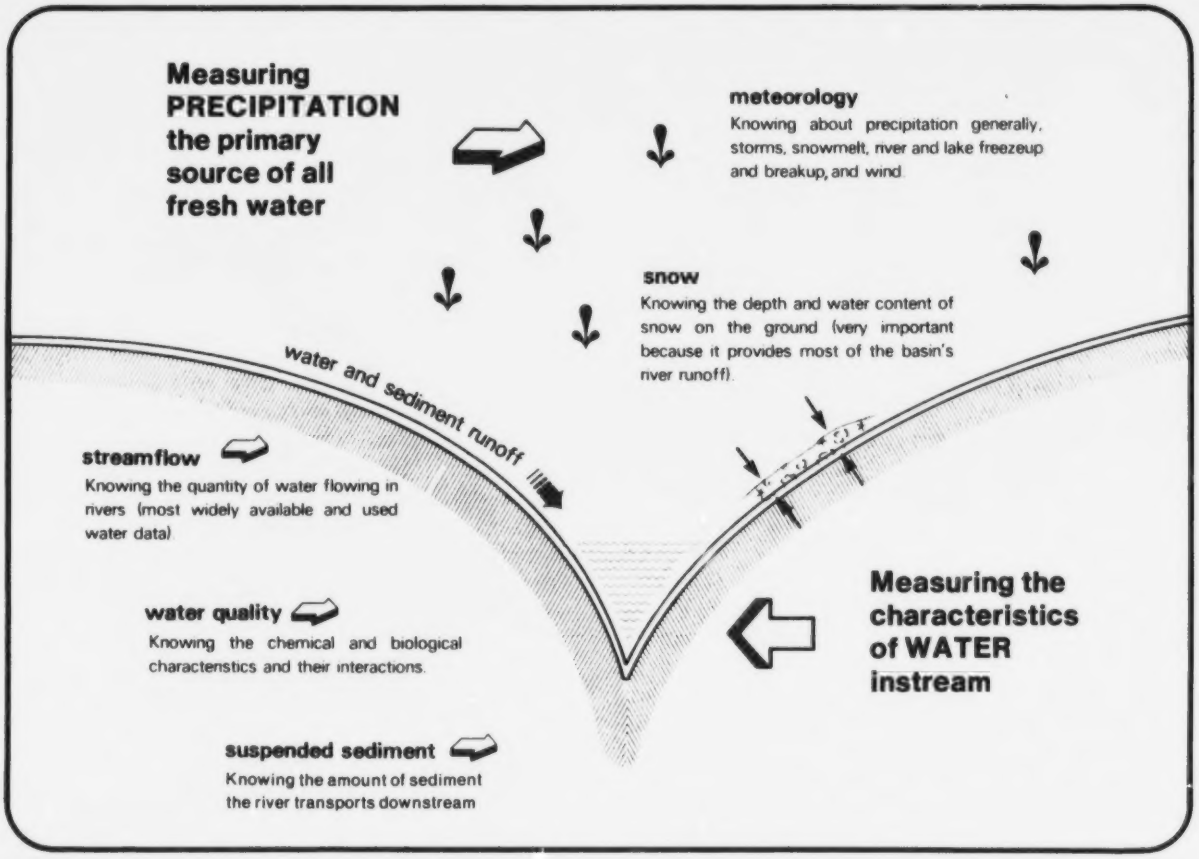

Measuring PRECIPITATION the primary source of all fresh water
meteorology
Knowing about precipitation generally, storms, snowmelt, river and lake freezeup and breakup, and wind
snow
Knowing the depth and water content of snow on the ground (very important because it provides most of the basin's river runoff)
water and sediment runoff
streamflow
Knowing the quantity of water flowing in rivers (most widely available and used water data)
water quality
Knowing the chemical and biological characteristics and their interactions
suspended sediment
Knowing the amount of sediment the river transports downstream
Measuring the characteristics of WATER instream

Figure 5.1
Water Data

Financial support has been easier to obtain for stations related to existing or planned projects, particularly in northern areas where there are few other immediate uses for such data and where operational costs are high.

Need for Integrated Network — Recognition of this situation, coupled with anticipation of certain major potential developments, led to the decision to identify the most critical shortcomings of the existing surface water data in the basin and to design a network of stations that will yield data for a reasonably complete picture of the basin's water resources.

Data collection is only an intermediate step. An understanding and overview of the basin's water resources can be obtained only by the manipulation and analysis of these data, by modelling their relationships, and by testing for complementary relationships and transferability. This is not immediately possible and was not a study objective. However, it is an integral part of the network concept and will be developed briefly in this chapter, so that consideration can be given to the required follow-up in the years ahead.

Integrated Network Design Objectives

The main objective of the integrated hydrometeorological network is twofold:

1. Inventory the hydrologic cycle in the Mackenzie River system to determine how much water there is, where it comes from, and how it varies with time.

2. Establish a baseline of essential data **before** more development occurs. This is a valid need for hydrologic and design purposes, but an absolute necessity for determining possible environmental impacts. Due to the wide variations in hydrologic conditions, anything less than 10 to 15 years of record at one location is generally insufficient. This emphasizes the importance of maintaining a basic network throughout the basin for the foreseeable future.

The integrated network is not intended to provide detailed or site-specific information for engineering or environmental purposes, although it may incidentally do so. It can be likened, in a rather simplified manner, to a general geological survey. A geological survey indicates the potential mineral resources and explains the overall geology of an area, but usually does not provide the detailed information needed for actual exploration or development. However, there is a major difference between geological or other resource surveys and baseline hydrometeorological monitoring. The former are stationary and vary only in location, whereas water resources vary in both location and time.

The network design must keep the eventual uses of the baseline data in mind. These include:

a. environmental studies;

b. monitoring of water availability at certain critical points and times (in alluvial areas, deltas, and shallow river reaches, among others);

c. regional analysis for preliminary design and evaluation purposes; and

d. water monitoring at provincial and territorial boundaries for administrative purposes.

The first of these extended objectives will also be served by geophysical and biological baseline data; however, because of the crucial role of water in nature, water and meteorologic data play a key role in environmental studies and environmental impact assessments.

C. Network Analysis

Design of the Mackenzie River Basin water data network was above all pragmatic: existing stations formed the backbone of the integrated network, taking maximum advantage of the existing data base and equipment and procedures already in place.

The approach was as follows:

1. Previous network studies were reviewed and useful findings or recommendations applied.

2. Existing networks were examined and stations providing, or capable of providing, data important to the overall basin water budget were identified and designated as long-term basin network stations.

3. New stations needed to fill data gaps in the overall basin water budget were identified for each type of monitoring (Section D).

4. An integrated network combining all these stations was designed for optimal effectiveness and efficiency (Section E).

1. Previous Network Studies

Various planning reports for hydrometeorologic networks in Canada have been prepared since 1969. The effectiveness of network planning in general was found to depend on the compatibility of the method employed, the hydrologic nature of the area involved, and the type, extent, and reliability of existing data. Because of the shortcomings in the basin's existing data base, attempts in the 1970's to apply sophisticated network evaluation and data transfer techniques to the hydrometric network were largely unsuccessful.

Basic to all the recommended networks are data transfer techniques that allow extrapolation of data from one network or type of data to another. The need for appropriate techniques was mentioned earlier and is discussed later in this chapter.

2. Existing Networks

Five types of water data are now being collected under separate and essentially uncoordinated programs. They are water quantity, snow, meteorology, sediment, and water quality. The fact that they developed in response to site-specific needs, available resources, and existing technology makes them quite different from the planned and integrated network sought in this study. Therefore, in this report the term "integrated network" will be used.

The individual existing networks (Table 5.1) were examined from four points of view: user needs, data

Table 5.1

Existing Water Monitoring Networks

Number of Stations by Subbasin

A = existing stations recommended for retention in integrated network
B = other stations

Station Purpose	Lake Athabasca		Peace River		Gr. Slave Lake		Liard River		Gr. Bear Lake		Mackenzie River		Mackenzie River Basin	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Hydrometric														
. baseline	39	5	40		16		6		5		19		125	5
. baseline/specific	19	7	13	4	13		21		2		11		79	11
. specific		20		23		10		12				7		72
Snow	21	5	35	5	19		33				6	1	114	11
Meteorology														
. baseline	11		11		5		6		1		10		44	
. baseline/ supplementary	8		12		2		9				1		32	
. other		69		84		16		10				6		185
Sediment	16	5	14		2		3				2		37	5
Water Quality	2		2		3		1		2		4		14	
	116	111	127	116	60	26	79	22	10	-	53	14	445	289

correlations, station coverage, and station purpose.

User Needs A questionnaire on all aspects of data and monitoring needs was sent to the main users of water data. The emphasis in the replies was on immediate and local data needs. This confirms the low priority generally given to the baseline data needs for basin analysis and planning by individual agencies and users. However, a number of very useful suggestions were made.

Data Correlations A series of statistical correlations was undertaken for mean monthly flows at all hydrometric stations in each subbasin to determine the ability to predict streamflow at one location by using records collected elsewhere.

The resulting correlation coefficients are generally poor because the present network is not of sufficient density to enable the transfer of data from one existing station to another, let alone to an ungauged area. The results do indicate to some degree where the inadequacies are greatest.

Station Coverage The inefficiency common to many long established networks can be traced to their growth as a series of stop gap measures in responding to specific demands for data. At the same time, prescribing uniform densities of station coverage is unrealistic because river basins differ greatly in size, hydrology, physical features, and degree of development. Nevertheless, it is interesting to compare the densities of some existing networks with the very general density guides of the World Meteorologic Organization (Table 5.2). It shows that the existing hydrometric network in the Mackenzie River Basin is certainly an "economy" network compared with similar undeveloped areas.

Station Purpose One of the most important steps in the network analysis was to determine the original and present purpose of existing stations, and from that to identify those stations essential for a baseline network (Table 5.1). This assessment was governed very much by practical considerations such as the type and quantity of historic information available, experience and familiarity with the stations, and analytical understanding of the role and value of the stations. For example, a long period of record of one station may have to be weighed against the better, but shorter record of another station.

Difficult judgments were required because there has been no systematic analysis of the available data in the subbasins. For example, the only analysis of a hydrologic system in the basin was done in the oil and tar sands area of Alberta. Such detailed analysis tends to be done only

Table 5.2

Hydrometric Network Comparisons

Basin	Number of stations per km^2
Red Deer River, Alberta	1:1 000
North Saskatchewan River, Alberta	1:1 100
Volga River, USSR	1:1 300
Oka River, USSR	1:4 600
Yukon River, Yukon Ter.	1:6 800
Mackenzie River Basin	
existing network	1:8 800
proposed network	1:7 100
WMO Guide (1980)	
minimum network	1:20 000
optimum network	1: 5 000

when there is a pressing need; yet without the benefit of such an analysis it is difficult to determine the adequacy of the present data. This emphasizes the importance of good judgment in dealing with imperfect information. It also points out the need for a systematic hydrologic analysis for the rest of the Mackenzie River Basin.

The subbasin totals for the integrated network and the "other" stations at the bottom of Table 5.1 corroborate the point made earlier that in the more developed subbasins like Lake Athabasca and Peace River, a much greater proportion of existing stations is devoted to specific rather than baseline network purposes.

Adequacy of Existing Networks — There are significant and critical gaps in the existing networks. Since there is very little capability to transfer data from one geographic area to another, or to generate one type of data from another, additional stations are needed. Where and how the gaps in each of the existing networks could best be filled is discussed in Sections D and E.

D. Component Networks

Following network analysis, the next step was to design separate water quantity, snowcourse, meteorologic, sediment, and water quality networks, incorporating the existing baseline stations identified for this purpose, and adding new stations. Complete descriptions of these component networks are contained in Supplements 4 and 5 to this report. They form the basis for the integrated network; however, in themselves they are only an intermediate stage of the design process and would serve no useful purpose by being repeated here.

The purpose of this section is to highlight the characteristics and limitations of each component network and briefly relate how these affected the design of the integrated network.

1. Hydrometric Network

The existing hydrometric or water quantity network is actually administered separately for each province and each territory by a different hydrometric coordinating committee. The costs in British Columbia, Alberta, and Saskatchewan are shared by the federal government and the respective province, whereas in the Yukon and Northwest Territories they are shared by the federal departments of Environment and Indian Affairs and Northern Development. Because this cost sharing is based on the purpose of the stations (federal only, federal-provincial/territorial, and provincial/territorial), there was a general appreciation of the purpose of various stations before this study began.

The first step in the design of the hydrometric network was to select the existing stations that would be useful in a long-term basin network, regardless of whether they served exclusively a baseline purpose or a combined baseline/specific purpose. Gaps in coverage and the best locations to fill these gaps were identified. The new stations, together with the existing baseline and baseline/specific stations identified earlier, constitute the component hydrometric network.

2. Snowcourse Network

Snow measurements are used to predict runoff volumes and the potential for snowmelt floods. Snow depth and density are used as an index of the amount of snow in the particular location, rather than as an absolute

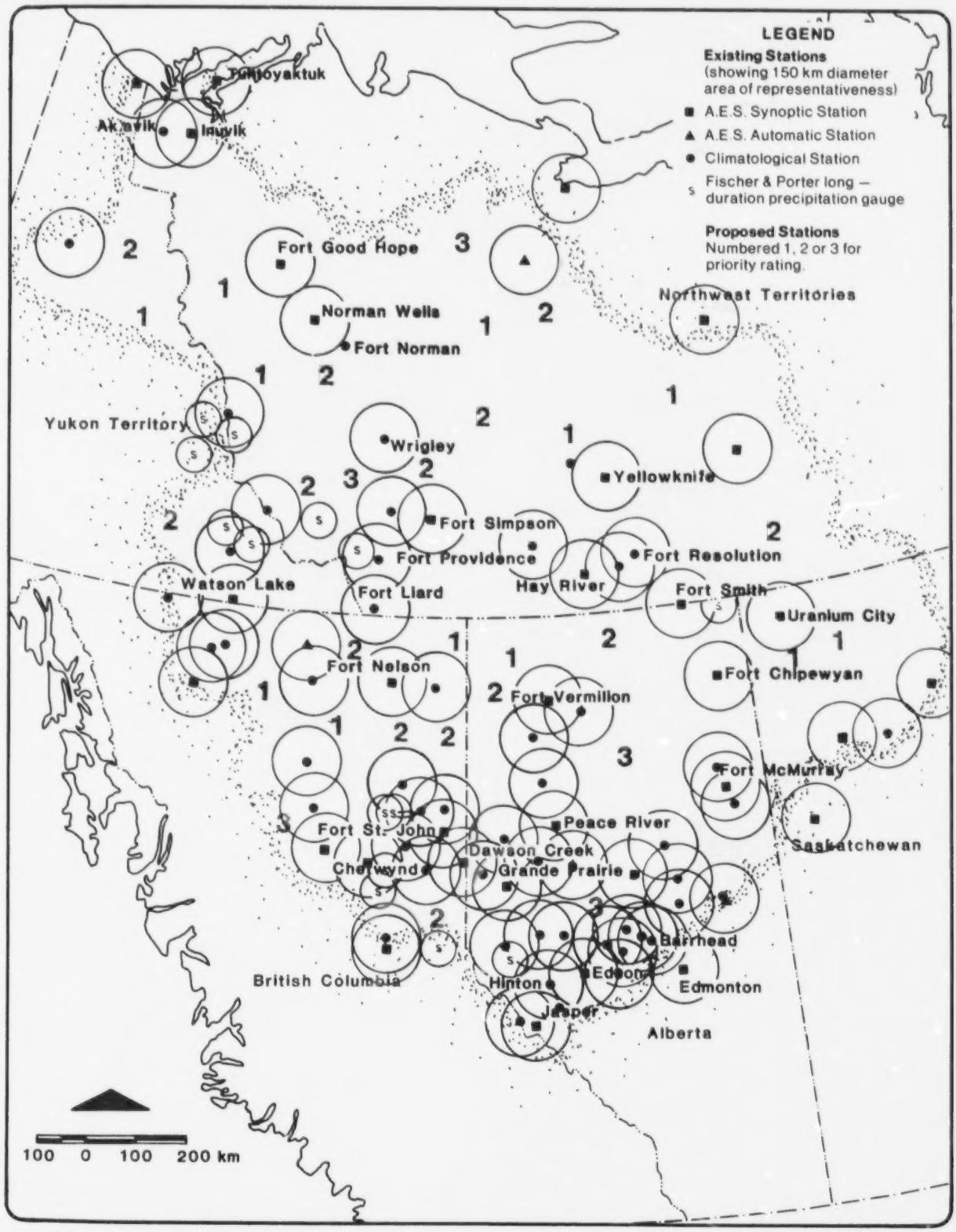


Figure 5.2

Meteorologic Station Priorities

measure. They are also used as a measure of winter precipitation at higher elevations where it is impossible to maintain precipitation gauges.

Collocation of snow courses and meteorologic stations is recommended in certain areas, particularly where an additional snow course is to be established at a higher elevation to assess snow-elevation relationships. In some cases, snowcourse stations are recommended as backup for meteorologic stations. Once acceptable correlations between snow courses at higher elevations and collocated snowcourse and meteorologic stations in valleys have been established in an area, it may be possible to reduce the number of stations there or relocate stations to meet new needs.

3. Meteorologic Network

A rudimentary hydrometeorologic network has existed in the Mackenzie River Basin since the late 1800's. The number of stations actually decreased in the remote areas around the turn of the century, but after 1910 the number of stations increased slowly until the early 1940's, when the network expanded rapidly to serve military requirements in World War II. These early records are remarkably continuous and accurate. Their main deficiency is that most stations were on the banks of major rivers and lakes. Being below mean basin elevation, they often do not provide representative regional values, particularly for precipitation and temperature data.

Advantage was taken of the existing network by first identifying stations that are best suited to a basin-wide network. The so-called synoptic stations qualify above all others, since their data are used to describe the major climatic features on a regional scale and to make national and international forecasts. Because these stations have an extended period of accurate data and are part of an international weather reporting system, they also have the highest probability of remaining active. They are supplemented by a number of other stations selected from a variety of ordinary and special-purpose stations operated in the basin.

Data gaps were determined on the assumption that a synoptic or climatological station measuring precipitation daily would be representative of the precipitation within a 75 km radius where topographical relief was less than 250 m, and within half that radius where the relief is greater. The shaded areas in Figure 5.2 show the gaps in coverage, and it is here that the 31 recommended new stations are located.

The most serious gap in the entire Mackenzie River Basin meteorologic network, from a hydrological point of view, is the Richardson and Mackenzie Mountain area, extending from the mouths of the Arctic Red and Peel Rivers southward to the North Nahanni River, and between the Yukon - Northwest Territories boundary and the Mackenzie Valley. This area adjoins a second major gap covering the southeast half of the Peel River watershed. The priorities shown in Figure 5.2 provide some guidance for implementation.

4. Sediment Network

Sediment monitoring in the Mackenzie River Basin is very recent. The first stations in the basin were established in the Athabasca and Peace River Subbasins as recently as 1966. Studies of the Peace-Athabasca Delta, the Mackenzie Valley Pipeline, and the Mackenzie Highway led to the establishment of a number of stations in the

Great Slave Lake, Liard, and Mackenzie River Subbasins in 1971 and 1972. Monitoring has been discontinued at most of these sites and is continued at other sites as finances and staff permit.

Sediment data collection is in its infancy for several reasons.

First, sedimentation incorporates four complex processes which are dependent on many factors: erosion, transportation, deposition, and compaction. Transportation of sediment, the main area of concern in this study, can be either in suspension or as bed load rolling and sliding on the riverbed, or as a combination of suspension and bed load. Sediment in suspension in one area may move as bed load in another. The former can be determined more easily and accurately than the latter, but the techniques are still rudimentary for both and the difficulties of making these measurements in large remote rivers will remain.

Second, there are no guidelines for planning large-scale sediment networks.

Third, the paucity of data and high cost of sediment collection and analysis favour a site-specific or project approach rather than the basic network approach envisaged for the basin.

The criteria for the proposed sediment network reflect this rudimentary state of affairs. Monitoring should cover representative large and small basins and biophysical zones. A flexible approach to the frequency and type of measurement should be adopted, rather than a rigid designation of stations, to obtain as broad and as quick an appreciation of the sediment regime as possible. Flow-sediment relationships should be developed for different times of the year and for the rising and falling limbs of the hydrograph.

5. Water Quality Network

Water quality data are available for a much shorter period than hydrometric data, and the network is much smaller. The present network is so sparse that all existing stations were included as baseline stations in the integrated network design. A fairly rigorous analysis was made of the additional stations needed for a basin network, complete with a priority rating for the stations.

Priority River Reaches The first task was to determine river reaches that generally characterize a river system. The reaches with the highest priority for sampling are those with the highest number of tributaries. The location of the sampling sites within designated reaches was determined by several factors such as access to sites, existence of other monitoring stations nearby, and existing or potential development areas.

Political Boundaries Monitoring of waters crossing provincial and territorial boundaries is important because upstream water uses in one jurisdiction can affect downstream uses in another. Sampling at border locations is a high priority and was given equal weight to the first order stations identified above.

Deltas Deltas are ecologically sensitive areas and are vulnerable to upstream pollution. Monitoring water quality in the usually complex deltas would be very costly. Instead, sampling sites are proposed on the major rivers immediately above the deltas, to indicate the quality of water entering these sensitive areas. These sites were also given first order priority.

Impact Assessment One of the major purposes of the proposed integrated network is to provide baseline data to assist in assessing impact of future developments. A baseline network to monitor all individual developments would be too costly as well as unworkable. Therefore, sampling locations for this purpose have second priority and were restricted to locations in river reaches most likely to be affected by future development. These network data will be important for establishing trends in water quality and identifying areas or parameters requiring special attention in the more comprehensive and site-specific surveys and studies that would be initiated by the proponents of specific development projects.

Judgment Although the foregoing criteria may identify a station in a particular river reach, there may be valid reasons to relocate the site either up or downstream, or even to another river. For example, a first priority site may be identified on River A, which has a lower discharge than River B and perhaps no existing or proposed developments. Therefore, the site may be switched to River B. Other considerations are existing and potential pollution sources, proximity of other monitoring stations, representation of the main biophysical zones, and overall balance of the component water quality network.

E. Integrated Network Design

The integrated network design consists of 445 existing baseline stations and 158 proposed additional stations. The location of stations is shown by subbasin in Figures 5.3 to 5.8, and the network as a whole is summarized in Figure 5.9. The proposed network is described below.

Network Increase It is important to put the recommended increase in stations (158) in proper perspective. First, the increase is over and above a total of 734 stations, rather than only those 445 stations among them that were judged suitable for baseline network purposes (Table 5.1). The other stations (Column B in the table) continue for the specific purposes they are now serving, although some redundancies in heavily monitored areas may make it possible to reduce the number of stations somewhat (see Supplements 4 and 5). It should be mentioned that a variety of other, very special-purpose stations now existing in the basin were not counted at all in Table 5.1. For example, a number of meteorologic stations are operated by the Alberta Forestry Service, but since records are kept during the fire season only, the information is of limited value for the integrated network.

There are significant differences in the required number of additional stations between the subbasins, and between the five monitoring components within each subbasin (Figure 5.9). For example, the need for additional water quality stations stands out in all subbasins, while the need for sediment and snow-course stations is prevalent in the four northern subbasins. The greatest numerical increase is recommended for the hydrometric network, but on a percentage basis the greater increases occur in the components with the smaller number of stations. For example, the increase in water quality stations would be 178%, although the numerical increase is the smallest among the five components. These differences are not surprising, given the ad hoc development of the present networks.

Figure 5.3

Integrated Network —
Lake Athabasca Subbasin

Figure 5.4

Integrated Network —
Peace River Subbasin

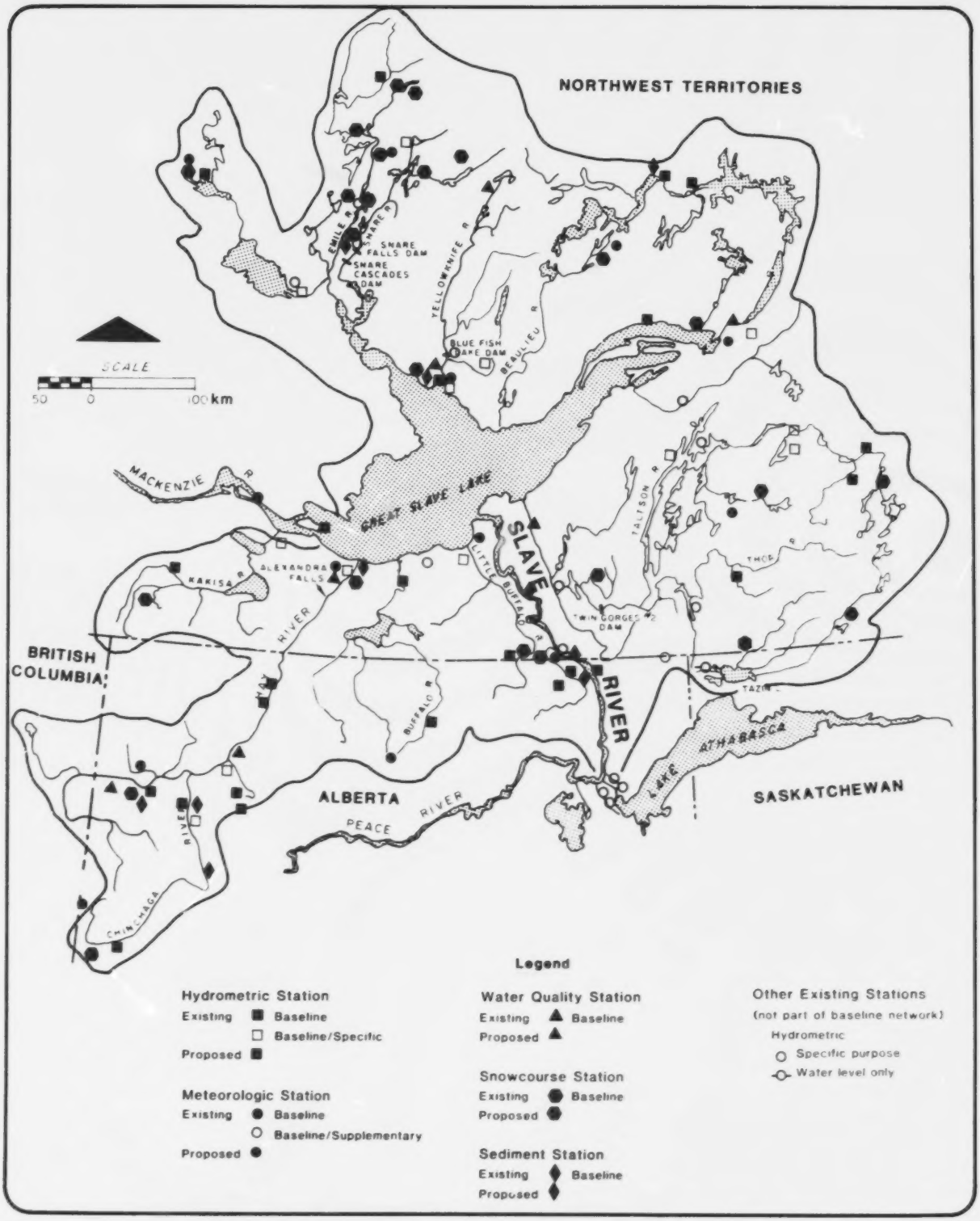


Figure 5.5

Integrated Network —
Great Slave Lake Subbasin

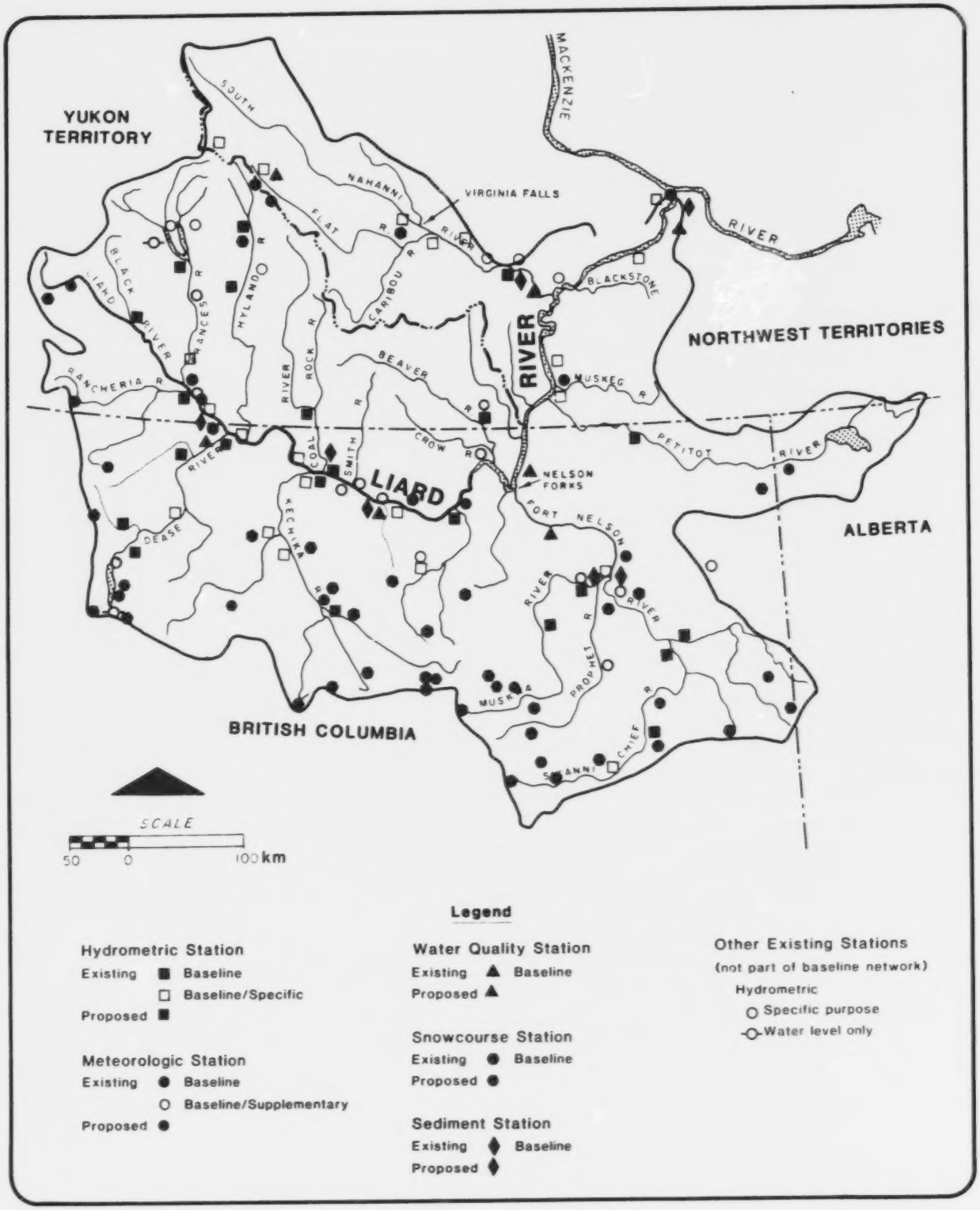


Figure 5.6

Integrated Network —
Liard River Subbasin

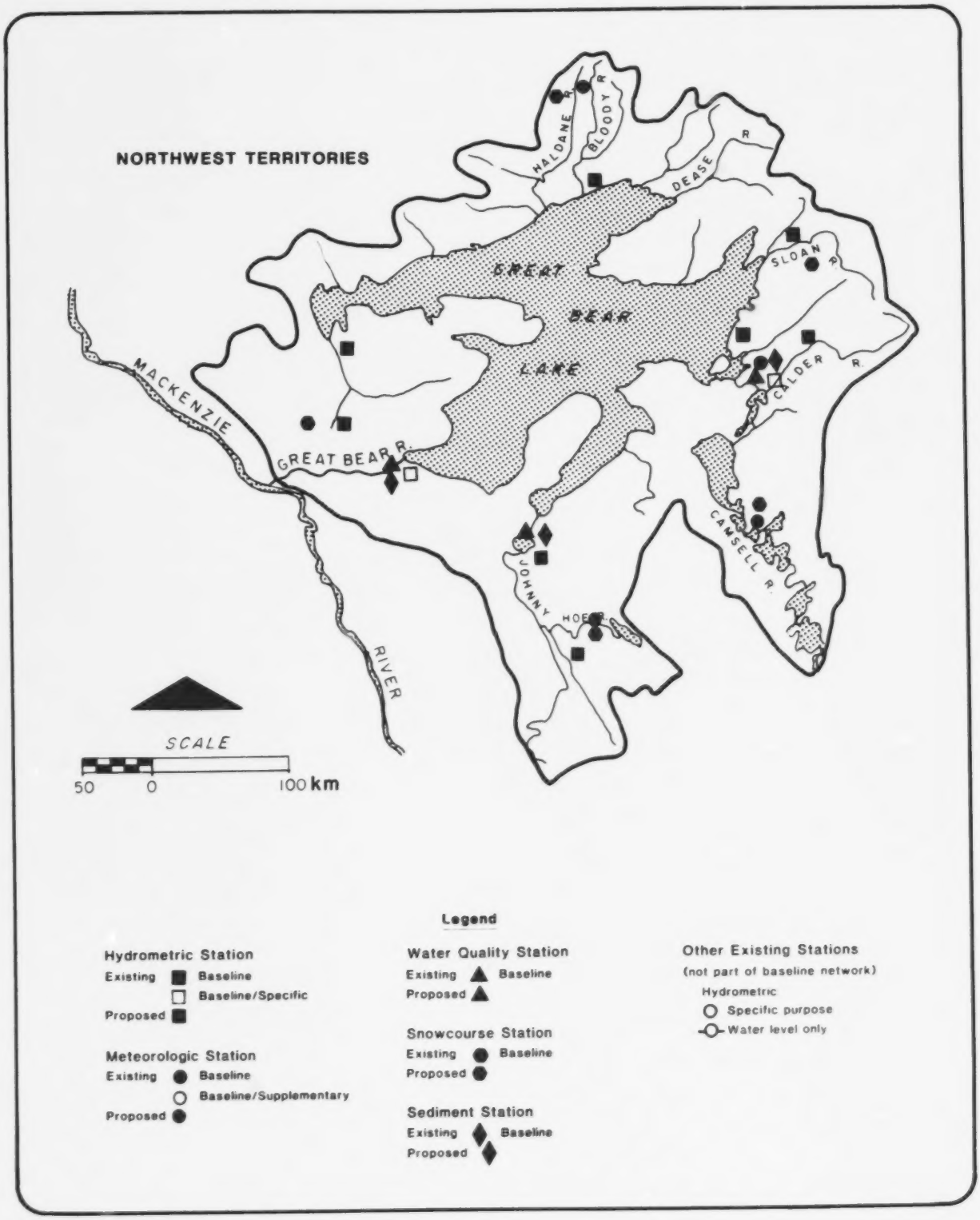


Figure 5.7

Integrated Network —
Great Bear River Subbasin

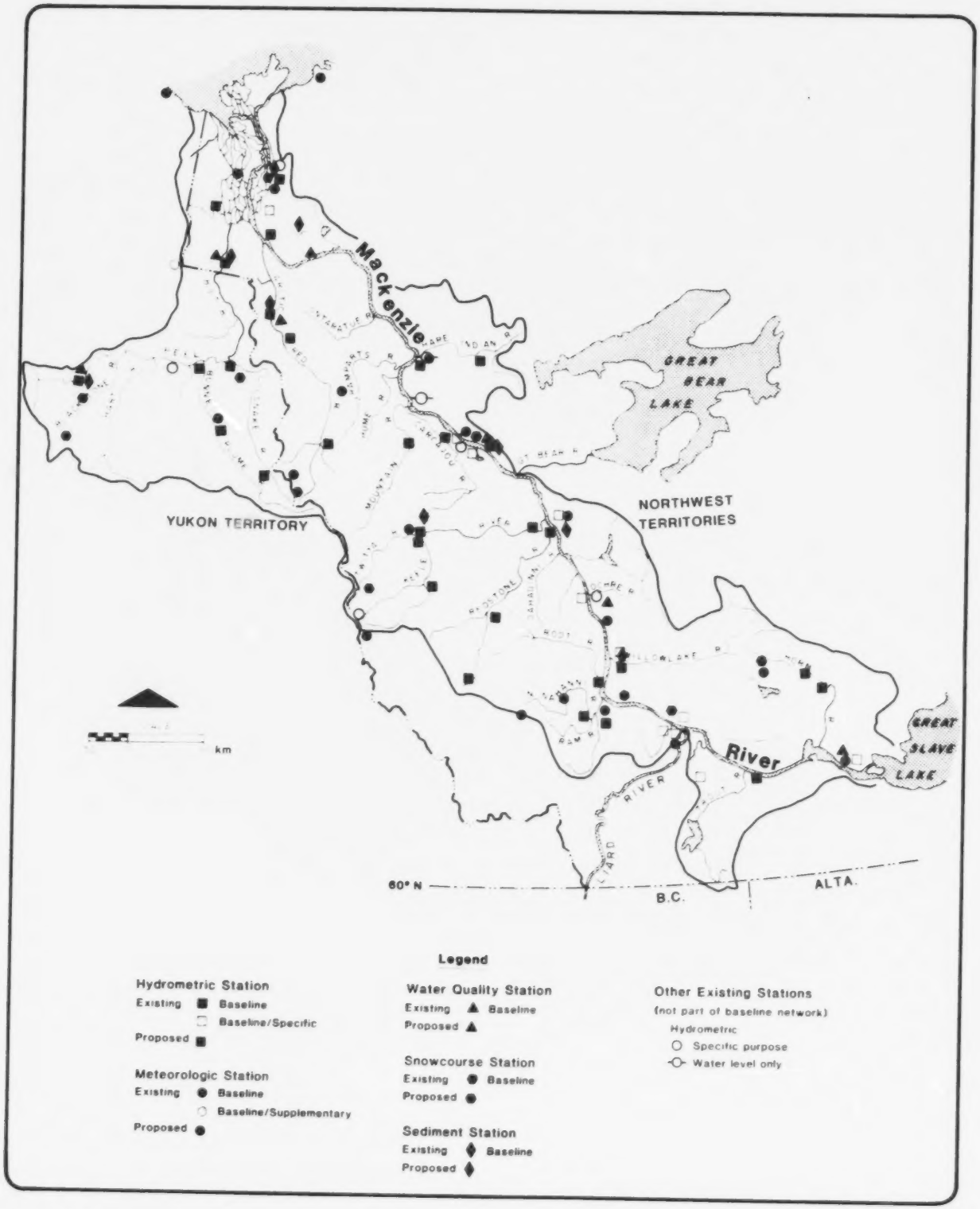


Figure 5.8

Integrated Network —
Mackenzie River Subbasin

Integrated Monitoring

The network proposed here constitutes only the first phase of developing an integrated network design. The network consists of five individual components, each designed with a basin overview in mind and regarded as part of a composite network for implementation purposes. This is a step in the right direction, but it is not yet integration. The emphasis in the near future has to be on acquiring more baseline data as soon as possible and at the lowest cost. Implementation of the proposed network will achieve that purpose.

Although monitoring is important, integration goes beyond the mechanics of monitoring. For example, the basin network needs to be operated according to a common set of standards and guidelines, which is obviously more difficult to achieve under the five different hydrometric coordinating committees than it would be by or on behalf of one agency for the basin as a whole. The main vehicle for integration, however, will be the analysis, interpretation, and interpolation of the various types of data and the development of correlations and models so that certain data can be transferred to other locations or substituted for each other. In other words, the integrated network design is not complete until both the data and the analytical and modelling tools exist for understanding the water resources of the Mackenzie Basin.

Implementation

The network design provides the first overview of the data monitoring needs of the Mackenzie River Basin. As such it is not an action plan, but a general blueprint that outlines substantial and long-term needs for the basin. An immediate start is urged on the necessary preparations for implementation.

1. Agency Review. All jurisdictions should review the recommended network and comment to the Mackenzie River Basin Committee on the network's scope and financial and operational implications of implementation.

2. Committee Review. The Mackenzie River Basin Committee should conduct a parallel review of the recommended network, incorporate agency comments, and provide guidance to the jurisdictions on all aspects of implementation.

3. Implementation Mechanism. The mechanism for implementation could take various forms:

a. a specific agreement to share the added cost of the integrated basin network;

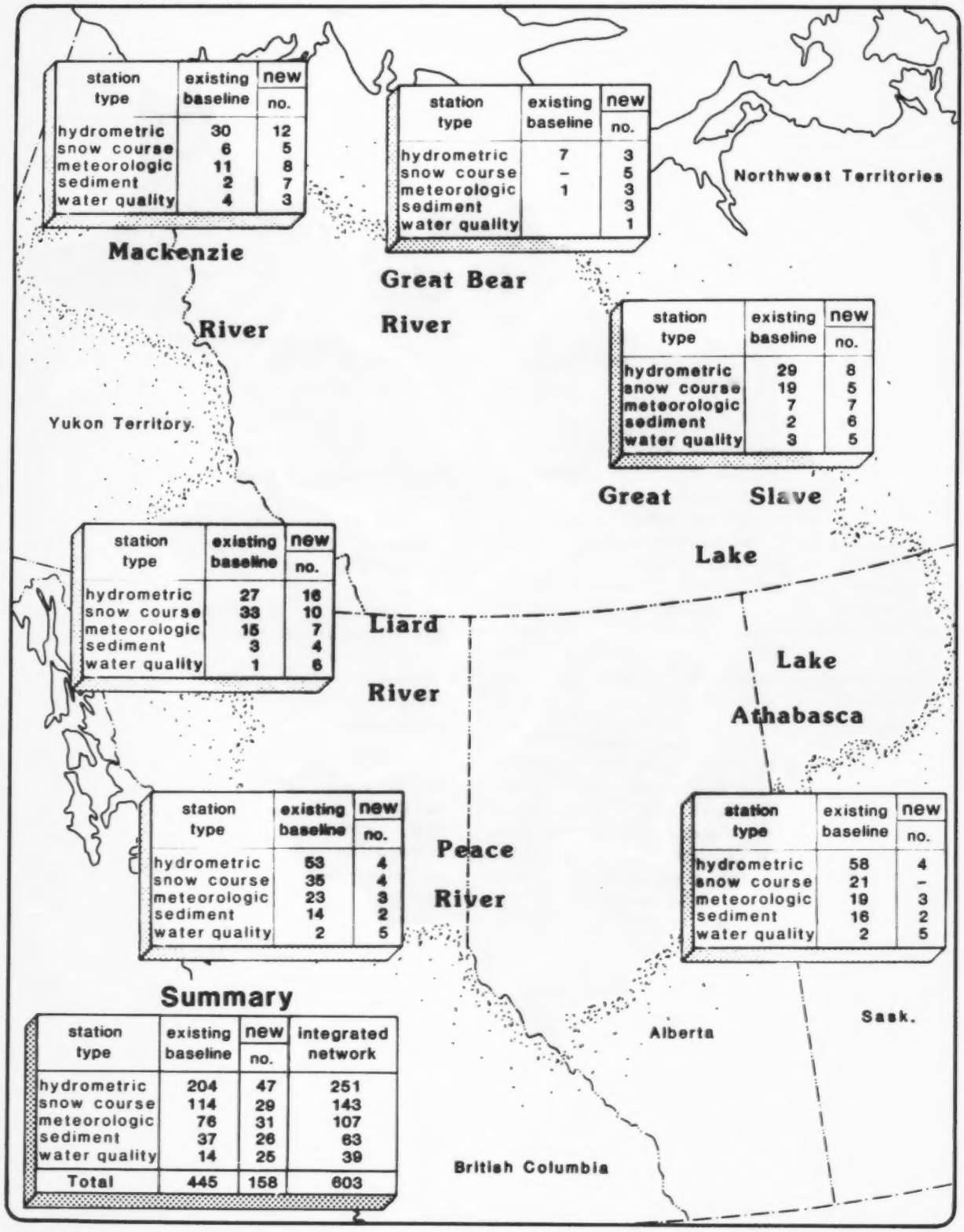
b. expansion of monitoring under the existing monitoring agreements; or

c. a general agreement on the interjurisdictional use of water.

Whatever the umbrella for implementation, a plan of action needs to be developed first.

4. Action Plan. One of the underlying goals in designing the network was to minimize the cost of the additional monitoring through collocation of new stations. Those working on the component networks generally agreed that the hydrometric network could serve as the basic network for the other four components. Many of the proposed new monitoring activities can be carried out either at the 47 proposed new hydrometric stations, or at the 204 existing baseline hydrometric stations. The general concept of collocation was of little help in coming to grips with specifically determining the types of monitoring that could be jointly located.

The ideal station would be a set of monitors for all five types of



station type	existing baseline	new no.
hydrometric	30	12
snow course	6	5
meteorologic	11	8
sediment	2	7
water quality	4	3

station type	existing baseline	new no.
hydrometric	7	3
snow course	–	5
meteorologic	1	3
sediment		3
water quality		1

station type	existing baseline	new no.
hydrometric	29	8
snow course	19	5
meteorologic	7	7
sediment	2	6
water quality	3	5

station type	existing baseline	new no.
hydrometric	27	16
snow course	33	10
meteorologic	15	7
sediment	3	4
water quality	1	6

station type	existing baseline	new no.
hydrometric	53	4
snow course	35	4
meteorologic	23	3
sediment	14	2
water quality	2	5

station type	existing baseline	new no.
hydrometric	58	4
snow course	21	–
meteorologic	19	3
sediment	16	2
water quality	2	5

station type	existing baseline	new no.	integrated network
hydrometric	204	47	251
snow course	114	29	143
meteorologic	76	31	107
sediment	37	26	63
water quality	14	25	39
Total	445	158	603

Figure 5.9

Integrated Network Summary —
Mackenzie River Basin

data, on the same platform or in the same building and sharing one power supply. However, local site conditions must be considered in the precise location of a station, so that it is impractical to make joint location an absolute requirement for implementing the basin network. Therefore, the choice of station locations first of all meant avoiding random locations altogether, and secondly, trying to locate stations as close as possible to each other, to minimize access and travel costs.

Only detailed site studies can show conclusively the feasibility of combining various monitoring activites. These studies involve considerations such as distance from the base of operation; type of vehicle used (fixed-wing aircraft versus helicopter, boat, or truck); frequency of visit; type of data or samples collected; and specific site and exposure requirements for each monitoring activity. Therefore, reconnaissance surveys are essential in the fine tuning of the network design. This process must be guided by an authority acting on behalf of the Committee, making sure that the basin overview goal is maintained and that operational and financial questions raised by operational agencies are taken into account.

Although the possible revamping of the existing networks was not a study objective, it would be useful to consider, in this later stage, the possible collocation of the "other" existing stations, be it to save costs or to improve the ability to correlate and interpret data.

F. Evaluation and Conclusions

The study showed that the design of an integrated network is more difficult and has to be more comprehensive than originally anticipated. First, the existing data base is so sparse that an evaluation of it provides few clues to the variability and representativeness that is needed for the design. Little more can be said than "There isn't enough." Second, there are few parallels in the world to draw on for experience and guidance. Third, the usefulness of the network will depend on the ability to analyze, interpret, and interpolate the data obtained. The accuracy and reliability of the network cannot be assessed, let alone improved, unless analytical tools are developed as well. Finally, such tools are needed to plan future network changes, and network expansions in particular, to maintain the balance between data and analysis, and to ensure that the data do add to the integrated body of knowledge of the basin's water resources.

The Committee recommendation to implement the proposed network arises directly from this study component. The supplementary development of analytical tools and models suggested here is considered a prerequisite for implementing another major study recommendation, which calls for hydrologic analysis and modelling for the entire basin. A balanced approach is advocated as the only way to meet the burgeoning demand for more detailed as well as more comprehensive water data at reasonable cost.

A. Development Potential
B. Study Results
C. Background to Recommendations

Implications for the Future

6

This chapter discusses the development potential of the basin and the water management problems that could arise when various types of development occur. These problems are viewed within the context of the basin's interjurisdictional nature, so some administrative structures for interjurisdictional water management in other parts of Canada are examined. Study results are discussed in terms of their completeness, and some important subjects not covered under the study program are identified.

A. Development Potential

The main types of development with implications for water are water resource, mining, and oil and gas projects. They are described below.

Water Resource Possibilities — From an economic point of view, the largest existing and potential use of water in the basin is hydroelectric power production. The first large project was the W.A.C. Bennett Dam on the Peace River in British Columbia. Several other large hydroelectric developments are being studied; most prominent are those on the Slave, Peace, and Liard Rivers (Figure 6.1).

Hydroelectric dams are constructed on major rivers because of their potential for producing electricity. In some cases they provide additional benefits such as flood control. On the other hand, the reduction in high flows by a big storage reservoir can seriously degrade the alluvial ecosystems downstream. Fall and winter flows downstream of a hydroelectric dam are higher than under natural conditions, with consequences for freezeup, breakup, and ice jamming. The stability and safety of ice cover is reduced and this can interfere with winter transportation. Other downstream effects may include changes in water quality, sediment load, river regime, stream gradient, and water temperature. Dams can also obstruct fish migrations, to the detriment of that resource. Reduced bank stability along the reservoir can cause additional problems.

Projects to divert water from one river or basin to another have both benefits and costs. Diversions can serve beneficial purposes like increased hydroelectric power production, irrigation, and water supplies. Such projects can also cause changes in water quality, water temperature, sedimentation, water levels, water volume, and river regime in both basins. Where the donor and recipient basins possess different species of plants and animals, the effects of interchange between them are often unpredictable, and therefore undesirable.

The natural conditions of rivers and lakes may also be changed by channel improvements and flood control projects.

Mining Possibilities — Development of the ample mineral resources of the basin (Figure 6.1) could have significant impacts on the water resource and the environment as a whole.

Under strict regulation, mining is no longer as deleterious to the environment as it formerly was.

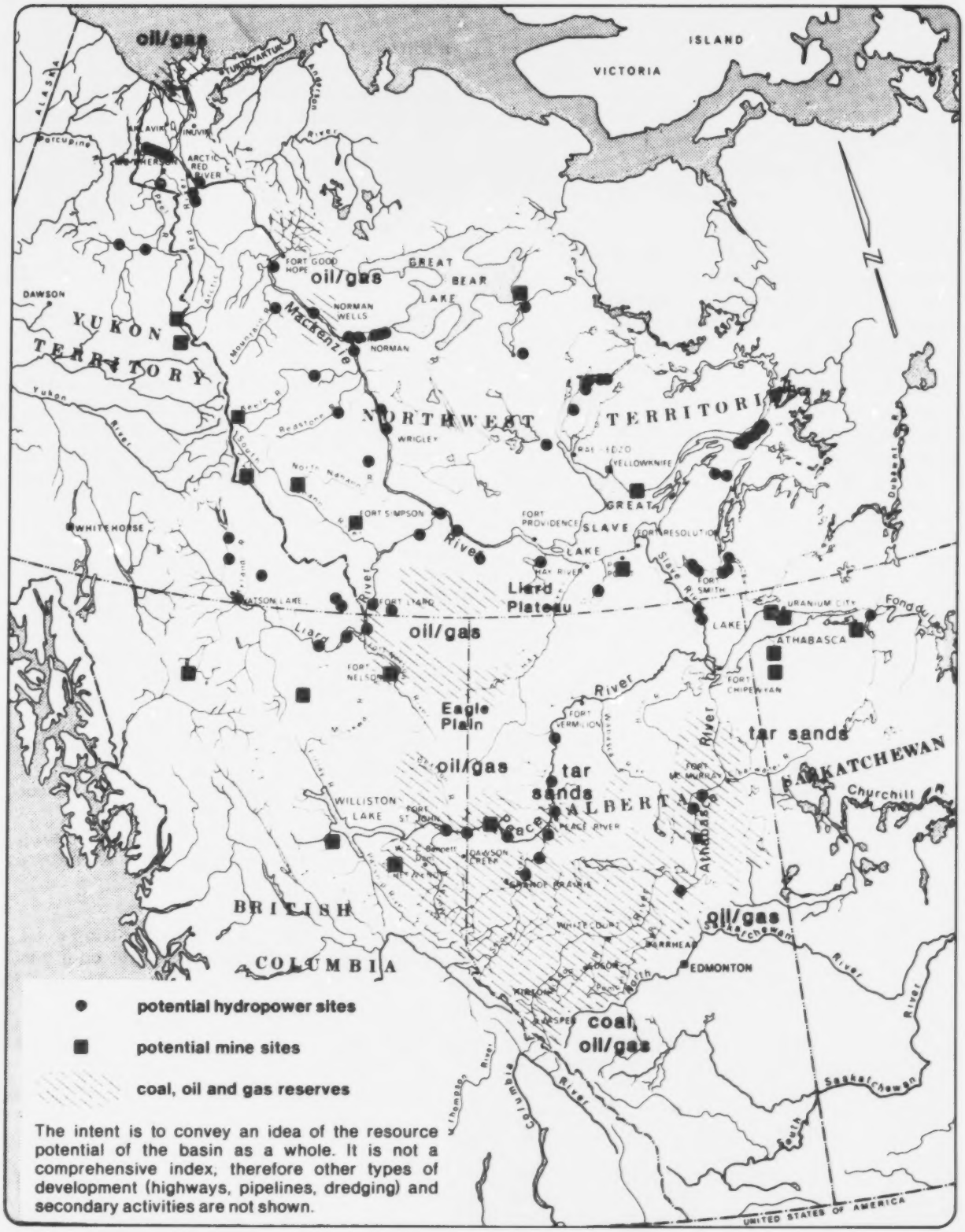


Figure 6.1

Selected Development Possibilities

The greatest hazard still is that of downstream contamination from tailings, tailings pond discharges, and residual processing reagents. Some of the toxic substances that may be present are free cyanide, metal-cyanide complexes, copper, lead, zinc, cadmium, arsenic, and mercury. Deep-well disposal of mine wastes is not always an effective method, as it can result in contaminants getting into the groundwater and eventually contaminating surface water distant from where the wastes were discharged. Fish populations are at particular risk from mining wastes because high concentrations of suspended solids can clog spawning gravels and suffocate eggs.

Uranium mining in the basin can cause several problems. The excavation of large quantities of soil and rock hastens erosion and hence increases siltation. Also the acid ore treatment process can negatively affect the chemical balance of nearby surface waters. Escape of radioactive waste is another potential problem.

Federal and provincial regulations establish standards for the quality of mining effluents. Standards are normally based on the best practicable treatment technology currently available. Although modern methods can greatly reduce the toxicity of most effluents, harmful chemical substances may still escape and poison organisms downstream, or contaminate them through long-term, low-level exposure. New production processes must be introduced only with the greatest caution as their effects, particularly on the aquatic life of northern climatic zones, are largely unknown.

There are large coal deposits in the headwaters of the Peace, Athabasca, Peel, and Yukon Rivers. Environmental problems with coal operations concern tailings, impoundments, waste rock disposal, and air emissions. Slurry pipelines for coal transport could "export" significant quantities of water.

Oil and Gas Possibilities

The Athabasca, Cold Lake, Peace and Wabasca tar sand deposits are the largest known hydrocarbon reserves in the basin and in Canada (Figure 6.1). These plus large coal deposits, recent oil and gas discoveries, and the existing production areas make the Mackenzie Basin the most significant energy production area in the country.

The development of these reserves may pose hydrocarbon and metal pollution problems. It will also require large quantities of water. For example, it is estimated that 4% to 10% of the mean annual flow of the Athabasca River will be required for synthetic crude oil production from the tar sands. The many more large plants anticipated in the future could cumulatively strain locally available water supplies during periods of low flow. Concern exists for the effects on surface water and groundwater, as well as for the potential acid precipitation from the sulphur dioxide emissions of processing plants. The most immediate effect is likely to be on the lakes of the Precambrian Shield of northern Saskatchewan, but many other areas could also be affected. The particular concern is cumulative effects because the reserves are so large and processing is likely to be on a huge scale and over a long period of time.

The development of these primary oil and gas resources will further change the basin through the influx of people, growth of new and existing population centres, and ancillary developments such as oil and gas pipelines, highways, transportation corridors, and increased river transportation. Domestic, industrial, and municipal water supply will become

a growing issue, along with sewage disposal, water for recreation use, and aesthetic considerations.

B. Study Results

This was the first study to examine the water resources of the basin as a whole. It illustrated that the major rivers, deltas, lakes, and biological resources are related to one another. They cannot be understood fully in isolation from each other or from the rest of the basin.

A network of hydrometric, snow, meteorology, sediment, and water quality monitoring stations was designed, which, if implemented, will provide necessary baseline information for effective water resource management. A computer model of the flows in the major rivers of the Mackenzie system was developed, from which the effects of water resource projects on water levels and flows downstream can be determined.

Through study of the alluvial ecosystem, a better understanding has been obtained of the forces and processes that physically shape northern floodplains and deltas, and the role these processes play in creating and maintaining a prolific and abundant variety of flora and fauna in alluvial areas. The study results also illustrate how the existing species and the relationships between flora and fauna depend on naturally fluctuating water flows and levels on the main rivers of the Mackenzie system.

New baseline information was obtained for the important spring ice breakup in the Liard River Subbasin. Study results include a description of the breakup process, ice jamming, and erosion by scouring in the major tributaries of the Liard River Basin, and confirmation that the Liard River normally causes the Mackenzie River ice below Fort Simpson to break up early. The Liard River was also confirmed as a prime contributor of suspended sediments to the Mackenzie River.

Although some conclusions about the effects of early breakup on the Mackenzie River and its delta are offered, additional investigations are required to determine quantitative relationships and to describe the role of early breakup in the maintenance of alluvial areas along the lower Mackenzie River and in the Mackenzie Delta.

Scientific information was obtained for two important sensitive areas, the Slave River Delta and the Athabasca Sand Dunes, about which little was previously known. Information on the physical and biological resources of these areas and their sensitivity to changes in the associated water regimes is now available. Existing information for 37 other sensitive areas in the basin was brought together and analyzed.

Some 1500 publications were abstracted and entered in the WATDOC computer referencing system. Most of these publications are in the library of the Boreal Institute for Northern Studies at the University of Alberta.

C. Background to Recommendations

The development of the basin's resources will invariably require water, and affect and strain this resource in some areas. The growing water use competition in the basin also requires better management.

Therefore, the question of how the jurisdictions can best cooperate must be addressed.

Water Use Competition Many human demands relating to navigation, fish, wildlife, recreation, hydroelectric power, industry, irrigation, and municipal water supply will all compete for the same water and impose different and conflicting requirements. Hydroelectric projects, navigation, and certain manufacturing industries demand large volumes of water, with quality a consideration of lesser importance. Recreational uses, particularly fishing, and municipal water supply demand reasonable volumes of water of high quality.

What complicates the situation most of all is that a jurisdiction wishing to pursue one or more developments within its boundaries could alter potential water uses in neighboring jurisdictions by changing downstream flows, levels, or water quality. Some uses, such as wildlife habitat, particularly in delta areas, are dependent on naturally fluctuating water regimes and the constant processes of erosion, transportation, and deposition of sediments. Maintenance of important delta areas such as the Peace-Athabasca, Slave, and Mackenzie Deltas will require constraints on the extent to which flows upstream can be regulated for other purposes.

Agreements The question is: **How can the existing and potential uses of the waters of this large basin be managed equitably, so that accepted environmental values in each jurisdiction will not be jeopardized?** The experience of more settled and developed areas of Canada may provide some guidance.

Boundary Waters Treaty Act. A series of confrontations over water use around the turn of the century convinced the Governments of Canada and the United States that water use problems along the international boundary are better solved through a permanent institution than through bilateral negotiations only. The Boundary Waters Treaty, signed in 1909, established the International Joint Commission. The Commission is composed equally of Canadians and Americans who conduct their business as a single body, not as separate national delegations representing their respective governments. They seek common impartial solutions in the mutual interest of both countries. Over the years the Commission has dealt effectively with more than 100 cases which have been brought before it.

Prairie Provinces Water Board. Runoff from the eastern slopes of the Rocky Mountains makes up about 80% of the supply for the southern rivers of the prairie provinces. These rivers flow eastward across Alberta, Saskatchewan, and Manitoba to empty into Hudson Bay. Custody of the water in this common river system by several jurisdictions can give rise to many problems in administering water use.

Upon the transfer of water resource administration from federal to provincial jurisdiction in the 1930's, the potential for conflicts over upstream and downstream water use among western provinces was recognized. On July 28, 1948, Alberta, Saskatchewan, Manitoba, and Canada signed an agreement establishing the Prairie Provinces Water Board. The principal purpose of the Board was to develop a formula for the apportionment of the waters of the Saskatchewan River system among the provinces party to the agreement. Agreement on apportionment among Board members was not to be easily achieved, and allocation of water on a project basis was adopted as an interim measure. Eventually, on October 30, 1969 a Master Agreement was signed by the four governments. The Master Agreement set forth a formula for the

sharing of the waters of rivers flowing eastward across inter-provincial boundaries. Each province agreed to ensure that 50% of the water entering the province across its western boundary, together with 50% of eastward flowing water originating within the province, would flow into the adjoining province downstream.

In other words, the agreement permits Alberta to consume 50% of the natural flow of a river before it enters Saskatchewan; Saskatchewan may consume 50% of the remainder, and 50% of the added flow rising within its boundaries; and Manitoba receives the remainder. Thus each jurisdiction has a right to use an agreed portion of the shared water supplies and can plan its use accordingly.

The Master Agreement also reconstituted the Board and broadened its terms of reference to include, among other things, the administration of apportionment, and studying and advising with respect to the quality of water crossing interprovincial boundaries.

Proposal for a Mackenzie River Basin Agreement

These examples indicate that cooperation is feasible and that a formal agreement is a suitable framework within which effective water management can take place.

The volumes of water crossing provincial and territorial boundaries in the Mackenzie River Basin each year are substantial (Figure 6.2). The resource development potential of the basin is also substantial, although relatively undeveloped. **Now is the time to consider a transboundary water management agreement. Further developments will narrow the choices and raise the potential for conflict. Effective management can be best assured through a formal agreement between jurisdictions.**

Other Water Management Needs

Management in any form requires a reliable water resource data base. The results of the Mackenzie River Basin Study offer a first step in providing this information.

Implementation of the water data gathering network designed in this study would offer meaningful water quantity information for water management. Use and refinement of the computer model of the river system will be necessary. However, the data network and computer model alone cannot provide all the needed information on the basin's water resource. A basin-wide analysis of precipitation, streamflows, and lake levels is also required to complete the picture satisfactorily.

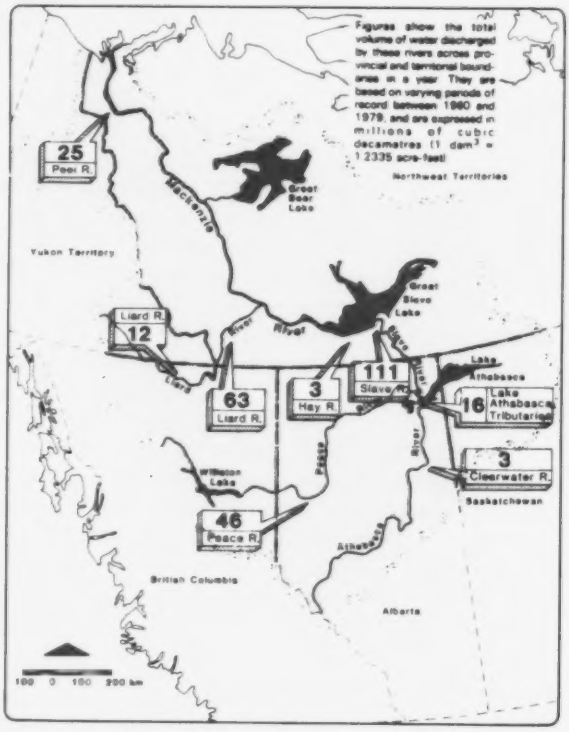


Figure 6.2
Major Streamflows across Boundaries

The results of the spring breakup study need to be complemented by information from monitoring a period of high flows. A similar program of investigations should be started on the lower Mackenzie River from Fort Simpson to the Mackenzie River Delta.

The Mackenzie River Delta is perhaps the single most important sensitive area in the basin. Existing knowledge of the delta is fragmentary. Studies are needed to fill identified data deficiencies.

There are significant data deficiencies related to fish spawning in the inner delta and marine mammal activity in the outer delta. The interaction between the Mackenzie River and the Beaufort Sea in and around the delta is also important and lacking in formation.

Three recommendations of a more general nature should be recognized . The WATDOC data base should be updated regularly to maintain its usefulness. Individual jurisdictions conducting environmental impact assessments of development proposals within their boundaries should consider the interests of neighbouring jurisdictions. They should also expedite the availability of new information on resources and proposed developments.

Recommendations

7

The Mackenzie River Basin Committee makes the following recommendations:

1 **It is recommended that the jurisdictions at an early date conclude an agreement through which transboundary water management issues such as minimum flows, flow regulation, and water quality can be addressed at jurisdictional boundary crossing points in the Mackenzie River Basin, and which establishes a permanent board to implement the provisions of the agreement.**

There is an urgent need to negotiate reasonable rules governing water flowing from one jurisdiction to another, and to adopt them by formal agreement. The challenge of treating potential and existing water uses as well as environmental values equitably in each jurisdiction is difficult but is being met elsewhere. For example, the achievements of the Prairie Provinces Water Board and of the International Joint Commission attest to the value of such formal cooperation and the growing need for it over time. At such an early stage of development, nothing would be more opportune for this large and important region of Canada than an agreement allowing orderly water resource development with an acceptable level of environmental protection.

2 **It is recommended that the proposed integrated long-term network of hydrometric, snow, meteorologic, sediment, and water quality stations outlined in this report be implemented.**

Effective long-term management of the basin's water resources cannot be undertaken without adequate baseline information. It is also likely that water quantity and water quality objectives will be required at the interjurisdictional boundaries. A meaningful period of record for such data is a necessary prerequisite for such objectives.

The network will have to be phased in, but a number of stations could be established without delay. When fully implemented, the network should remain stable and in operation for a period of at least ten years.

3 **It is recommended that precipitation, streamflow, and lake levels be evaluated for the entire basin to determine variability over time and space, and that the relationships among all parts of the water budget be analyzed and modelled.**

There has been little evaluation of the existing data base because of its sparseness and the relatively short period of record. There is a need to make use of all available information to better understand the variability of these phenomena over time and space and to develop techniques for synthesizing data for areas where no information is now available. There is also a need to better understand the relationships between precipitation and runoff, so that maximum use can be made of one type of information for predicting another.

4 **It is recommended that the computer model of the river system developed in this study be continually refined and updated as additional hydrometric data are collected and as changes occur on the river system.**

The computer model provides a much needed management tool for the evaluation of hydrologic effects downstream of water resource projects. It is also useful in identifying hydrometric data errors and deficiencies. The model must be updated and new hydrometric data incorporated in order for the model to remain useful.

5 **It is recommended that the monitoring and analysis of the processes involved in spring breakup and sediment transport in selected streams in the Liard**

River Subbasin be continued until several high-flow years have been documented, and that the study area be extended to include the Mackenzie River from Fort Simpson to its mouth.

The results of the spring ice breakup study are based on a three-year period of below-average flows in the Liard River and its main tributaries. For a more complete understanding of breakup, monitoring should be carried out in the Liard River Subbasin for a period of high-flow years, and should be extended to the lower Mackenzie River. This is important for assessing the effects of future developments on river transportation, alluvial areas, and the Mackenzie Delta in particular.

6 **It is recommended that a comprehensive study of the Mackenzie Delta be undertaken to determine the relationships among the processes of delta change; and the vegetation, fish, and wildlife resources; and the hydrologic regime.**

The Mackenzie Delta is complex and provides some of the most productive fish and wildlife habitat in the basin. It is unlike any other area of the basin because all the effects of upstream water resource development will accumulate there. The delta and the Beaufort Sea also have a large potential for oil and gas production which can affect the delta directly.

7 **It is recommended that each jurisdiction in the Mackenzie River Basin, when considering a project proposal, follow an environmental assessment process that accommodates the interests in other jurisdictions in an equitable manner.**

Six jurisdictions are involved in the basin. Thus the equitable use of the water resource requires that the assessment of a project's feasibility by a jurisdiction include the views and concerns of affected jurisdictions.

8 **It is recommended that the program of abstracting documents regarding water and related resources in the Mackenzie River Basin for entry in the national water document data base (WATDOC) be continued.**

The established Mackenzie Basin data base in the WATDOC computer referencing system will become outdated, unless new reports and documents are included.

9 **It is recommended that the jurisdictions recognize the increasing level of interest in the resources of the Mackenzie River Basin and ensure that any new information on the resources and their development is made available to each other and to the public in a timely fashion.**

Development in the Mackenzie River Basin hitherto has been modest in scale. Increasingly, power utilities, energy corporations, mining companies, and governments are identifying large resource potentials in the basin and encouraging their development. Consequently, the area is also a focus of concern for regulatory agencies and the people of the basin. Information and expertise exchanged should be as current as possible.

Appendices

A. Slave River Delta

B. Athabasca Sand Dunes in Saskatchewan

C. Computer Model of the River System

D. Study Program Documents

E. Glossary

A. Study Area
B. Delta Formation and Hydrology
C. Water Quality
D. Fish and Macroinvertebrates
E. Aquatic Furbearers
F. Migratory Birds
G. Evaluation and Conclusions

Slave River Delta

Appendix A

River deltas are among the most productive aquatic habitats in the world. The productivity of these ecosystems is largely due to the high nutrient content of the alluvial deposits, the periodic replenishing of these nutrients by flooding at various times of the year, and the rich and diverse shoreline habitats created by extensive channeling.

The Slave River Delta is one of the three major deltas in the Mackenzie River Basin. However, until recently it has been virtually overlooked by environmental and ecological studies. Because of the general sensitivity of deltas to environmental change and the lack of information regarding the aquatic ecology of the Slave River Delta, a study was initiated to obtain baseline information concerning the potential importance and sensitivity of its biological resources. This appendix describes the formation of the Slave River Delta, its significant physical features and biological resources, and their susceptibility to potential changes in the hydrologic regime. Areas where further information is still needed are identified. A more complete discussion is found in Supplement 6 to this study report.

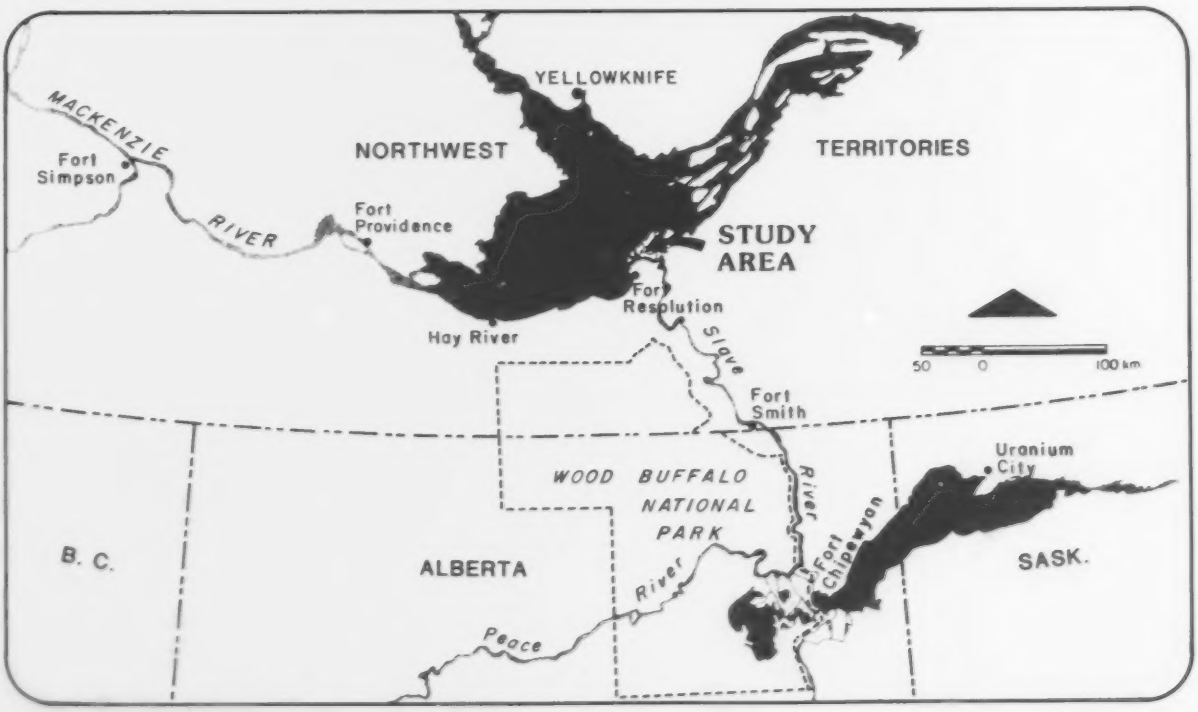


Figure A.1
Study Area
Slave River Delta

A. Study Area

The Slave River Delta is located on the south shore of Great Slave Lake at 61° 15'N and 113° 30'W, immediately northeast of Fort Resolution, N.W.T. (Figure A.1). The active portion of the delta occupies a wedge of approximately 75 km^2 which stretches for 20 km along the south shore of Great Slave Lake and extends 10 km to the head of the delta in the south. This portion of the delta consists of four major channels separated by low, very flat basins (Figure A.2). The channel banks are typically low near the lake, but tend to become higher farther inland in the older portions of the delta. Generally, the channels are deep and the bottom drops away very quickly from the banks. Channel depths range from 7.5 m to 32 m in the four major channels and 2 m to 3.5 m in the minor unnamed channels.

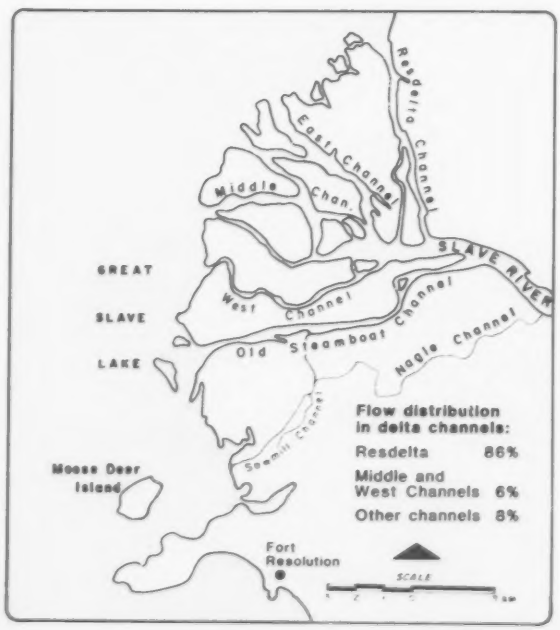


Figure A.2
Major Channels
Slave River Delta

The Slave River Delta is located within the subarctic climatic zone and as such is characterized by long, cold winters and cool, short summers. The mean daily temperature for the month of January in Fort Resolution is approximately -25°C, while the daily temperatures during the summer months rarely exceed 15°C. The area is considered semi-arid with a mean annual total precipitation of 28 cm.

Soils in the delta consist primarily of alluvial deposits whose composition ranges from grayish-brown, calcareous, loamy sand to a silty, clay loam. These soils occur in the siltbars and flats of the delta, seldom more than three metres above the river level, and are frequently flooded. In the more stable parts of the delta, soils consist of a thin organic layer covering calcareous loam and permafrost which occurs at depths below 80 cm.

The vegetation of the delta follows the patterns of typical wetland plant succession (Figure A.3). In the outer delta, where large deposits of alluvial soil are found, the vegetation is characterized by species such as horsetail, cattail, and sedges. Farther inland, in the less frequently flooded areas, these species are replaced by more successionally advanced plants such as willows which predominate in the middle portions of the delta. Finally, higher above the high water levels and levees, other woodland species such as balsam poplar and alder become abundant. Stands of white and black spruce occur well above the average high water mark.

B. Delta Formation and Hydrology

Two studies of Slave River Delta formation and hydrology were

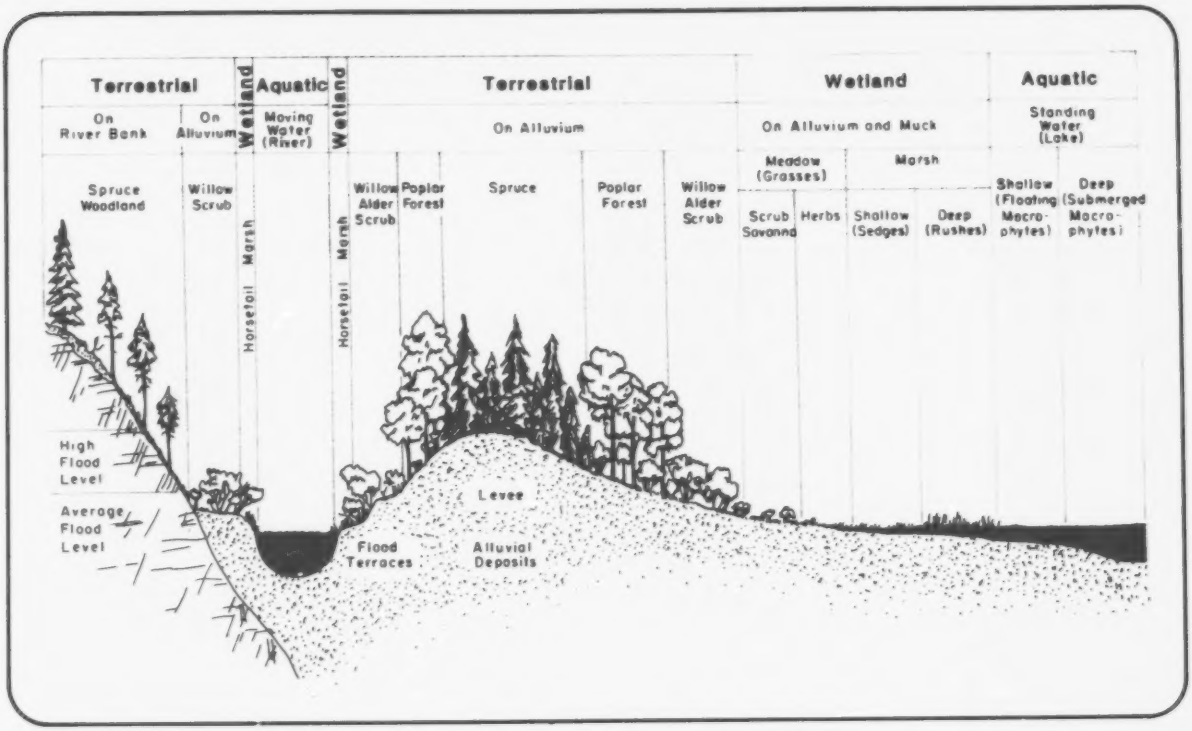


Figure A.3
Typical Vegetation Succession
Slave River Delta

undertaken. Aerial photographs taken during 1930 to 1979 and Landsat images for the period 1972 to 1980 established the changes in delta morphology over time and provided an understanding of the processes associated with delta formation. In addition, data from a three-year hydrology study of the Slave River Delta provided information concerning flow distribution through delta channels, water level fluctuations, and sediment loads. A detailed description of delta formation, geomorphology, and hydrology is found in Supplement 6.

The Slave River Delta is an arcuate delta, the shoreline of which has been modified by the waters of Great Slave Lake. The older eastern portion has been blunted and smoothed by wave action and currents, while the active western part is typical of an unmodified arcuate delta. The delta has been advancing into Great Slave Lake over the past several thousand years and has moved an average distance of 1.5 km since 1930, a rate of 3.0 km per century.

This advance appears to have occurred in a series of steps, with intervals of rapid growth followed by periods of little or no advance or even local retrogression. During the period 1930 to 1946 the delta advanced a distance of 0.5 km to 2.5 km (Figure A.4) but from 1946 to 1973 the advance was limited to less than 1.0 km. Examination of landforms in the Slave River lowlands reveals that five such episodes of delta building occurred over the last several thousand years. Each of these active building periods

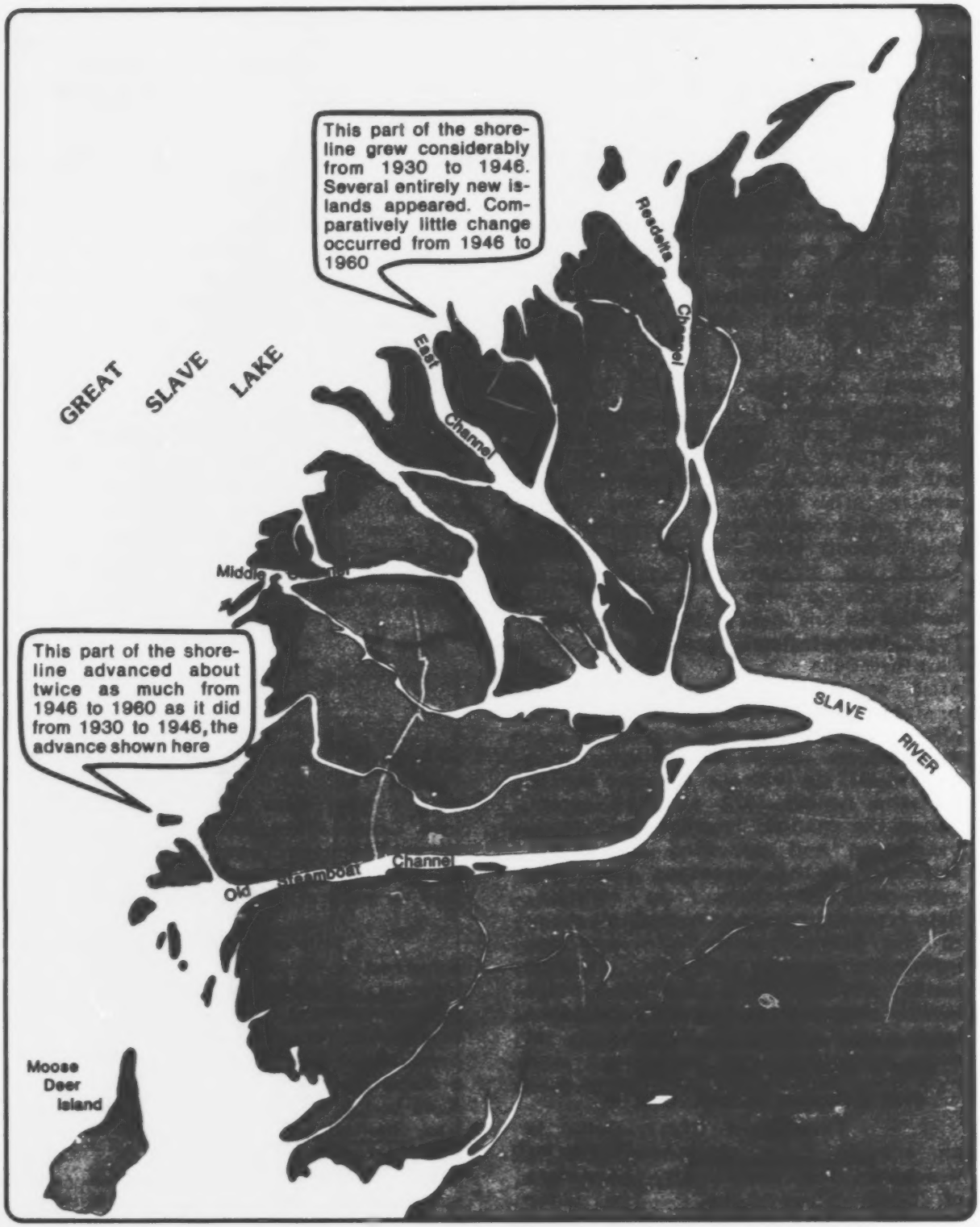

This part of the shoreline grew considerably from 1930 to 1946. Several entirely new islands appeared. Comparatively little change occurred from 1946 to 1960
GREAT SLAVE LAKE
East Channel
Resolute Channel
This part of the shoreline advanced about twice as much from 1946 to 1960 as it did from 1930 to 1946, the advance shown here
SLAVE RIVER
Channel
Moose Deer Island

Figure A.4

Advance of Slave River Delta

1930-46

1 Sediments are distributed for a considerable distance along the lake shore on both sides of the delta
2 Boundary between the Interior Plain and Precambrian Shield
3 Pine Point mining area

Figure A.5
Sediment Plume
Slave River Delta

was eventually terminated by wave and current erosion and marked by the formation of beach ridges. Distribution of abandoned beach ridges shows that beach ridge formation and shore erosion occurred on one side of the channel, while active building took place simultaneously on the other. The same process is currently underway in the modern Slave River Delta between Fort Resolution and the mouth of the Taltson River. On the east side of the main channel of the Slave River, beach ridge formation and shoreline erosion are taking place, while on the west side active delta construction is in progress (Figure A.5). These events indicate that

delta progradation takes place on both sides of the river, and alternates between periods of sedimentation and advancement and periods of erosion and shoreline regression.

Delta hydrology and sedimentation are the primary factors controlling the vitality of life in the Slave River Delta. Study results show that 86% of the total flow during the open-water period was carried by the Resdelta Channel. The middle and west channels accounted for about 6% of the flow and the remaining 8% of the flow was carried by the other minor channels. During the winter months more than 90% of the flow passed through the Resdelta Channel while flows close to zero were reported in some of the smaller channels. Since 1930 there has been a dramatic shift in flow distribution toward the Resdelta Channel.

Water level fluctuations of up to three metres occurred between spring high water and fall low water conditions. Two distinctly different spring breakup periods were observed during the course of the study. The 1979 breakup occurred late in the season, with high water levels and subsequent flooding of much of the delta. Water level fluctuations of two to three metres during this period resulted from ice jams in the spring flood. In contrast, the 1980 breakup was relatively early and gradual with low flows and minimal flooding.

Water levels in the smaller channels were observed to fluctuate up to 0.2 m when onshore winds prevailed. This wind setup was less evident in the larger channels and was virtually undetectable in the Resdelta Channel.

Limited suspended sediment data were obtained for the Slave River Delta immediately above the channel divergence. Comparisons between suspended sediment concentrations measured here and at Fort Smith indicated that the regularly measured Fort Smith data provide a good approximation of sediment loads flowing into the Slave River Delta. The highest daily suspended sediment load recorded at Fort Smith was 690 000 t, during the high water period in June 1979. Suspended sediment concentrations averaged 250 mg/L for the year and rose to 1000 - 2000 mg/L during the high water period in the spring. Mean annual suspended sediment loads for the Slave River since 1972 are in the order of thirty million tonnes. More than half of this input occurs during June and July, and the rest mainly in May and from August to October.

C. Water Quality

During the study, the water quality of the Slave River was monitored at Fitzgerald and in the delta (above Nagel Channel). A comparison of the results from the two sites indicates that there is no significant difference in quality between the two sites. Hence it appears reasonable to use the long-term records of the Slave River at Fitzgerald to comment on the water quality of the Slave River.

The Slave River contains moderate amounts of dissolved solids with typical values of total dissolved solids (TDS) ranging from 100 to 140 mg/L. The predominant ions contributing to these TDS concentrations, in order of decreasing importance, are bicarbonate, calcium, sulfate, sodium, magnesium, and chloride. Calcium is the principal ion contributing to the moderate hardness of these waters.

Suspended solids are present at moderate to high levels and peak values sometimes exceed 2000 mg/L during the high water period.

Most metals are present in

the waters of the Slave River at undetectable or very low concentrations. Two exceptions are iron and manganese (measured as extractables). Typical values range from 0.5 to 2.0 mg/L for iron and from 0.05 to 0.10 mg/L for manganese. These concentrations reflect the presence of supended sediment and are not expected to pose a problem to the aquatic environment.

Herbicides, picoloram, and most chlorinated hydrocarbons have never been detected in the waters of the Slave River. Only minute quantities of alpha-BHC, which is widespread in western Canada, have been detected. This relatively innocuous compound is not an environmental concern.

D. Fish and Macroinvertebrates

Investigations were undertaken to obtain baseline information concerning the life history of fish populations in the Slave River Delta; the physical, chemical, and biological characteristics of the delta's aquatic habitats; and the relative importance of these habitats to the fish resources of both the Slave River Delta and Great Slave Lake.

1. Benthic Macroinvertebrates

Bottom dwelling organisms such as the larvae of various insects, crayfish, clams, snails, leeches, and aquatic worms make up the benthic macroinvertebrate community, an integral part of the aquatic food chain. These organisms feed on decomposed organic matter, plants, or other animals and are, themselves, a source of food for fish. In addition, the sensitivity of some benthic macroinvertebrates to changes in environmental conditions combined with their sedentary behaviour makes them excellent biological indicators of environmental quality.

Unstressed, benthic macroinvertebrate communities are inherently stable in structure and composition. Stresses induced by changes in environmental quality result in the destruction of certain organisms and the proliferation of others. Therefore, by monitoring benthic communities and identifying the alterations in structure and composition that occur, adverse changes in the aquatic environment can be detected.

A total of 56 different types of invertebrates, representing 13 major groups, were collected from the Slave River Delta. Thirteen of these were found in both the major and minor channels, 30 were restricted to the major channels, and 13 were found exclusively in the minor channels.

The benthic community in the major channels was dominated by species of sludge worms (oligochaetes) and midge larvae (chironomids). Together these two groups accounted for 90% of the organisms collected. This is not considered unusual since the silty bottoms found in the major channels favour burrowing organisms. Community structure and composition varied with depth. Increasing depth resulted in a dramatic decrease in the numbers of organisms collected. Sixty-nine percent of the total organisms were collected in water less than one metre deep, while only three percent were found at depths exceeding five metres. Although total numbers of organisms decreased with depth, the opposite was true for community diversity. At depths less than one metre, oligochaetes and chironomids were dominant. However, at depths between one and two metres, the benthic community was totally dominated by oligochaetes

(72%). Beyond that depth, oligochaete numbers dropped off significantly and mayfly nymphs and caddisfly larvae became more important. When depths exceeded five metres, these two groups were next in importance to the chironomids. This is related, in part, to a higher incidence of sandy substrates, which are a less suitable habitat for burrowing forms.

In the minor channels, the benthic community was different. Although the dominant organisms were still oligochaetes (sludge worms) and chironomids (midge larvae), other groups such as blackfly larvae (Bezzia), water fleas (Daphnia), and fingernail clams (Pisidium) were also important.

2. Fish

Twenty-three fish species representing 13 families were found in the Slave River Delta (Table A.1). Overall the most abundant species was lake cisco, which accounted for nearly 70% of the total fish caught. Next, in order of abundance, were trout-perch, burbot, emerald shiner, goldeye, northern pike, lake chub, longnose sucker, and walleye. The remaining 13 species together represented only 3.6% of the total.

Major Species Major species were defined as those large enough to be captured in gill nets and those generally abundant or economically valuable. In the Slave River Delta these species included lake whitefish, cisco, goldeye, inconnu, northern pike, flathead chub, longnose sucker, burbot, and walleye.

The seasonal variation in gillnet catch per unit effort (a means of expressing relative abundance) of major species in each of the five main channels is illustrated in Figure A.6. Major species were generally five times more abundant in the lower Slave River and Resdelta Channel than anywhere else in the delta. The only exceptions to this were goldeye, flathead chub, and yearlings of most major species, which were evenly distributed throughout. Yearling inconnu, goldeye, and walleye were totally absent.

Variations in relative abundance of large fish are associated with upstream and downstream movements of major species through the delta

Table A.1

Fish Species Collected in Slave River Delta

FAMILY AND SCIENTIFIC NAME	COMMON NAME
Petromyzontidae	
Lampetra japonica	arctic lamprey
Salmonidae	
Orchorhynchus keta	chum salmon
Coregonidae	
Coregonus clupeaformis	lake whitefish
Coregonus artedii	lake cisco
Coregonus spp.	cisco - black fin
	cisco - white fin
Prosopium cylindraceum	round whitefish
Stenodus leucichthys	inconnu
Thymallidae	
Thymallus arcticus	arctic grayling
Hiodontidae	
Hiodon alosoides	goldeye
Esocidae	
Esox lucius	northern pike
Cyprinidae	
Couesius plumbeus	lake chub
Platygobio gracilis	flathead chub
Notropis atherinoides	emerald shiner
Notropis hudsonius	spottail shiner
Semotilus margarita	pearl dace
Catostomidae	
Catostomus catostomus	longnose sucker
Catostomus commersoni	white sucker
Gadidae	
Lota lota	burbot
Gasterosteidae	
Pungitius pungitius	ninespine stickleback
Percopsidae	
Percopsis omiscomaycus	trout-perch
Pericidae	
Stizostedion vitreum vitreum	walleye
Perca flavescens	yellow perch
Cottidae	
Cottus cognatus	slimy sculpin
Cottus ricei	spoonhead sculpin

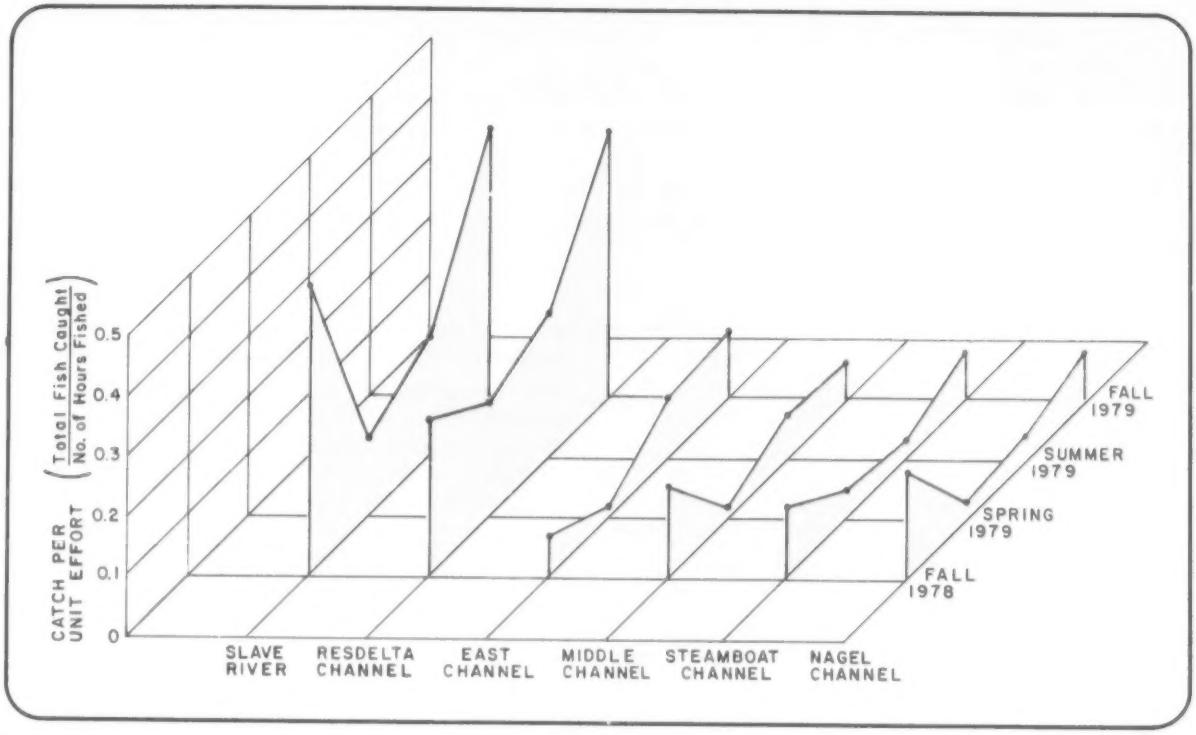


Figure A.6

Seasonal Variation in Fish Catch
Slave Delta Channels

(Table A.2). Peak numbers of fish recorded in the fall are attributed to upstream spawning migrations of cisco and burbot which coincided with downstream movements of northern pike, walleye, and longnose sucker. Similarly, increased relative abundance observed during the summer is due to the gradual upstream movement of inconnu and lake whitefish coupled with rising numbers of goldeye entering the delta from habitats farther upstream. There was no evidence of large concentrations of fish overwintering in the Slave River Delta.

Although few major fish species utilized Slave River Delta habitats for spawning, portions of the delta, particularly the Resdelta Channel and lower Slave River, were major spawning areas for burbot and cisco. In addition, the delta is considered to be an important corridor for the passage of large numbers of fish to their preferred spawning habitats located farther upstream. The base of the rapids at Fort Smith is suspected to be a major spawning area for lake whitefish, inconnu, longnose sucker, and walleye. There was no evidence of goldeye spawning in either the Slave River Delta or the Slave River. It is speculated that goldeye captured in the delta were immigrants from goldeye populations in the Peace-Athabasca Delta that moved downstream into the Slave River after spawning.

Minor Species For this study, minor fish were defined as all of the smaller fish present as well as any large fish that were rarely captured or of little economic value.

Table A.2

Seasonal Movements of Major Fish Species in the Slave River Delta

SPECIES	SEASON	DIRECTION	DESCRIPTION OF MOVEMENT
Cisco	Fall	Upstream	Movement to spawning areas No evidence of post-spawning movement
Lake Whitefish	Late Summer Fall	Upstream	Gradual movement to spawning areas
Inconnu	Late Summer	Upstream	Movement to spawning areas
	Fall	Downstream	Post-spawning movement
Goldeye	Late Summer	Downstream	Post-spawning movement
	Fall	Upstream	Movement to overwintering areas
Northern Pike	Fall	Downstream	Gradual movement during open-water season to feeding areas in delta
Flathead Chub	Fall	Downstream	Data too variable to support firm conclusion Suspect movement toward over-wintering areas in Great Slave Lake
Longnose Sucker	Midsummer	Downstream	Post-spawning movement
	Fall	Downstream	Secondary movement to over-wintering areas by fish that did not migrate in summer
Burbot	Late Fall Early Winter	Upstream	Spawning movement
Walleye	Late Summer	Downstream	Movement from upstream spawning and summer feeding areas

One arctic grayling and one round whitefish were captured during the study. In addition, several chum salmon including one ripe male were caught during October and November in the Slave River. Sixteen larval arctic lamprey were captured during the study; the majority of these were captured in the Slave River during June and July. Arctic lamprey are known to be parasitic on lake whitefish, lake trout, and inconnu; however, there was no evidence that these or any other fish captured had been attacked by lamprey.

Lake chub, emerald shiner, and trout-perch were the most abundant small fish in the delta and together accounted for more than 70% of the fish caught. These fish are an important forage species for larger fish.

The distribution of smaller

fish was different from that of the major species. While the East, Middle, Steamboat, and Nagel Channels were of limited importance for the majority of large fish, they were important feeding and rearing areas for small fish and young-of-the-year of larger species. The latter included northern pike, flathead chub, longnose sucker, and burbot.

The highest densities of minor species were recorded in shallow water habitats with extensive aquatic vegetation. This habitat preference was followed, in decreasing order of importance, by shallow water habitats with little vegetation; deep, sharply inclined areas with aquatic vegetation along the shore; and deep, sharply inclined habitats with little vegetation. Generally, lake chub, trout-perch, and emerald shiner were evenly distributed throughout the delta, although the first two showed a slight preference for the inner delta and the latter were more dominant in the outer delta.

Small fish were most abundant during the summer and their numbers declined steadily throughout the fall. Peak numbers of trout-perch and emerald shiner were observed in mid-July and late August, respectively. However, large numbers of lake chub were present during all three sampling periods (mid-June, mid-July, and mid-August).

Although lake chub, emerald shiner, and trout-perch were by far the most common, the following small fish species were also found in the delta: spottail shiner, pearl dace, white sucker, ninespine stickleback, yellow perch, slimy sculpin, and spoonhead sculpin. Together these fish made up slightly more than six percent of the total number of small fish captured.

E. Aquatic Furbearers

Muskrat (Ondatra zibethicus) is considered to be the aquatic fur bearing species of greatest economic importance to the indigenous people of the Mackenzie River Basin (Figure A.7).

Figure A.7
Muskrat
Slave River Delta

Aquatic furbearers of the Peace-Athabasca and Mackenzie Deltas have been studied extensively; however, very little was known about the aquatic furbearers of the Slave River Delta. Consequently a study was undertaken to gather baseline information on the muskrat populations of the Slave River Delta and to determine their sensitivity to alterations in the river regime.

It was found that selection of habitat for construction of muskrat houses is variable and depends on both hydrologic and climatic conditions. Habitat suitable for constructing typical muskrat houses (Figure A.8) exists primarily in the bays along the outer delta and in some of the depressions between the levees. Abundant growths of aquatic emergents in these areas were used by muskrats for both food and lodge construction. Muskrat houses were especially abundant during 1975-76; however, their numbers decreased throughout the study period. During aerial surveys conducted in the fall of 1978, 1979, and 1980, only 21, 18, and 26 houses, respectively, were found on the delta. Of these, less than 15% were determined to be active. Evidently standing water bodies of the delta, although nutritionally rich, provide inferior habitat for muskrats. The freezing of these areas during the winter made standing water bodies unsuitable locations for house construction. Consequently, these areas are important only during mild winters when they provide additional habitat for a temporarily high population.

Figure A.8
Typical Muskrat House
Slave River Delta

The lack of good long-term habitat for house construction necessitates the use of bank burrows. Bank burrowing in the delta was restricted to the channels because the configuration of delta lakes and perched basins precludes the construction of bank burrows. Abundant growths of aquatic plants along channel margins, combined with easy access to the underwater portions of emergent vegetation, made delta channels particularly attractive as winter habitats (Figure A.9). The

Figure A.9
Channel Habitat
Slave River Delta

suitability of these areas was further enhanced by declining water levels during the winter which formed an air space between the surface ice and the water. This allowed overwintering muskrats to forage for some distance under the ice and increased their chances of winter survival. Since superior habitats are those that enable successful overwintering, channel habitats are considered particularly important.

River regime in general and water levels in particular affect winter habitat utilization. When water levels are high, muskrats build houses

on lakes and on the outer delta similar to those found in other regions. When water levels drop, muskrats resort to the use of bank burrows such as those found in the Mackenzie Delta.

The extensive use of bank burrows created difficulties in determining abundance, distribution, and density of muskrats in the Slave River Delta. Variations in the number of muskrat houses from year to year or place to place do not necessarily reflect changes in population size since an unknown percentage of the population may have been occupying bank burrows. Nevertheless, a general statement concerning population status can be made.

Although muskrat populations follow a cyclic pattern of highs and lows, the specific mechanisms and environmental factors associated with this occurrence have been neither identified nor totally understood. Slave River Delta muskrat populations declined after a recent peak in 1975–76 and appear to have reached a low point in the cycle during 1978–80. It is speculated that this decreased muskrat abundance is related to unfavorable hydrologic conditions which made standing water habitats unsuitable. Results from the fall of 1980 indicate that the muskrat population has passed the low point and some recovery has taken place.

The reproductive potential of Slave River Delta muskrats appears to be high. The average number of young produced by an adult female was 17.8, 16.4, and 18.3 for the years 1978, 1979, and 1980, respectively, and it is likely that most females produced two litters of eight to nine young each year. Nevertheless, the possibility of females producing a third litter, particularly during abnormally long summers, should not be eliminated. Production estimates were determined from placental scar counts and it is possible that direct measurements of production would yield values lower than those reported here.

During the study, the survival rate of juveniles in summer and early fall was 35%. This unusually low survival rate may be due to a bias associated with the data collection technique which favored the capture of adults rather than juveniles. Generally, the muskrats of the delta appeared to be in good physical condition. Disease and parasitism did not have a significant effect on survival. The major cause of mortality during the summer months was predation by raptors and mink, while winter mortality was largely due to freezing of house sites and starvation. Trapping and hunting were also major causes of mortality, particularly for channel-dwelling muskrats. Muskrats inhabiting the lakes and bays of the outer delta were less susceptible to these pressures since they were virtually inaccessible to hunters during the shooting season.

Muskrat populations of the Slave River Delta are in many ways similar to those in the other major wetlands of the Mackenzie Basin. However, the variable climate and river regime of the Slave River Delta have forced the muskrat population to be more flexible, particularly in the utilization of winter habitats, as compared with muskrats of the Peace-Athabasca and Mackenzie Deltas. These two deltas are characterized by a set of climatic and hydrologic conditions that generally remain constant for extended periods. These constant conditions allow Peace-Athabasca Delta muskrats to live in typical muskrat houses year-round and Mackenzie River Delta muskrats to live solely in bank burrows. By contrast Slave River Delta muskrats are forced to respond to conditions that require the use of strikingly different habitats from year to year. Conditions favoring the inhabitation of typical houses may prevail in one year, change and favor

bank burrows the next, then return to the former conditions several years later. This alternating use of two major habitat types on the same delta is a unique adaptation of Slave River Delta muskrats.

F. Migratory Birds

The relative importance of the Slave River Delta as a breeding and staging area for waterfowl was determined by aerial and ground surveys conducted during the spring and fall of 1978 and the spring of 1979.

The Slave River Delta was used by an estimated duck breeding population of 5218 pairs; of these, 52% were dabblers (mallard, gadwall, widgeon, teal) and 48% were divers (canvasback, redhead, goldeneye, lesser scaup) (Figure A.10). Although breeding ducks were distributed evenly throughout the delta, there was a marked difference in the habitat preferred by the two types. Generally, dabblers preferred the outer, less stable portions of the delta, while diving ducks occurred mainly in the inner, more stable boreal-type ponds.

Figure A.10
Mallards
Slave River Delta

The Slave River Delta did not support as high a breeding population of ducks as reported in other areas of the Mackenzie River Basin. However, when numbers of breeding pairs per unit area are considered, duck breeding densities are similar to those estimated for the Peace-Athabasca Delta. No breeding pairs of geese were observed in the delta during the study.

Duck production in the delta was lower than expected, based on numbers of breeding pairs (5,218). Only 47 broods (201 ducklings) were observed during the 1978 field season. Seventy percent of the observed broods were dabbler species while the remaining 30% were divers. Both diver and dabbler hens with broods preferred habitats with heavily vegetated shorelines and stable water supplies. Ducks began incubation between May 28 and June 24 and hatching occurred between June 23 and July 17 during the 1978 and 1979 field seasons.

The Slave River Delta was of primary importance as a spring and fall migratory stop for waterfowl. Although duck utilization was low compared with other areas of the Mackenzie Basin, the Slave River Delta and the southern shore of Great Slave Lake were used by a large number of whistling swans and geese.

Fall migrating waterfowl were first observed in the delta during the last week in August, 1978. At that time the majority of ducks recorded were dabblers. Numbers of diving ducks increased between September 11 and 16, and the total number of ducks reached a

peak of 7635 on September 16. Goose numbers also peaked at this time, while maximum numbers of swans were not observed until September 23. The highest numbers of geese and swans recorded were 2169 and 1799 respectively.

Swans and geese preferred the habitats of the outer delta while ducks were observed in the numerous ponds, sloughs, and oxbows of the interior.

The presence of waterfowl in the Slave River Delta during the spring coincided with the appearance of open water. Ducks, mostly dabbler, were observed in peak numbers (3435) on May 14 when open water was first available, but the largest number of diving ducks (1313) was not observed until the end of May. Peak numbers of geese (3700) occurred just before the breakup of the Slave River. Swan staging extended over a longer period with maximum numbers (1339) occurring only after the delta was completely ice free.

The varied habitats available in the Slave River Delta also hosted a variety of non-game migratory birds (Table A.3). The most common of these was the yellow warbler. A maximum of about 3000 shorebirds was recorded on September 11 and of these, pectoral sandpipers, semipalmated plovers, and Baird's sandpipers were most abundant. Several incidental sightings of transient non-game migratory birds are noteworthy. Three American avocets were sighted in early June. These birds normally breed in the prairie region and are rarely seen in northern forests. In addition, a Caspian tern was sighted on a sandspit in the outer delta in July. Several sightings of these birds were recorded in the delta around the turn of the century, but now these birds are considered rare.

A variety of raptor species was observed in the delta during the study. These included the sharp-shinned hawk, red-tailed hawk, rough-legged hawk, golden eagle, bald eagle, osprey, marsh hawk, merlin, American kestrel, great horned owl, and short-eared owl. Most hawk sightings were occasional; however, marsh hawks were commonly seen foraging over the delta during the summer. The area was used for nesting by bald eagles, but only two of the three nests located were found to be active.

Table A.3

Non-Game Migratory Birds Common to the Slave River Delta

FAMILY AND SCIENTIFIC NAME	COMMON NAME
Podicipedidae	
Podiceps auritus	Horned Grebe
Charadriidae	
Charadrius semipalmatus	Semipalmated Plover
Scolopacidae	
Actitis macularia	Spotted Sandpiper
Erolia melanotos	Pectoral Sandpiper
Erolia bairdii	Baird's Sandpiper
Capella gallinago	Common Snipe
Tyrannidae	
Empidonax minimus	Least Flycatcher
Parulidae	
Vermivora peregrina	Tennessee Warbler
Dendroica petechia	Yellow Warbler
Dendroica coronata	Yellow-rumped Warbler
Geothlypis trichas	Yellowthroat
Fringillidae	
Spizella arborea	Tree Sparrow
Zonotrichia albicollis	White-throated Sparrow

G. Evaluation and Conclusions

1. Significance of the Delta

The biological significance of the Slave River Delta is attributable to the large number of highly productive and diverse habitats it provides in comparison with the surrounding boreal forest. The wetlands, channels, and sloughs of the delta function as a biological area which offers good breeding, rearing, and feeding habitats that would otherwise be unavailable.

The Slave River Delta is located on four migratory bird flyways

of North America and consequently is of significance. The delta in general and the outer delta in particular provide excellent staging habitats for large numbers of migratory waterfowl. It is estimated that more than 30 000 whistling swans pass through the area annually en route to the Mackenzie Delta. Furthermore, many habitats of the Slave River Delta are suitable for duck production. These become very important when dry conditions in the prairie pothole region to the south, where ducks normally breed, force breeding ducks to move northward in search of stable water conditions.

Regionally, the delta is important to both migratory birds and Great Slave Lake fish populations. The Slave River Delta is one of the three main waterfowl breeding areas in the region.

Although duck utilization of the delta was low in comparison with that of the Peace-Athabasca Delta and the Mills-Beaver Lakes area, utilization of the delta by swans and geese is comparable with that of the other two areas, per unit area, and may possibly be higher.

The delta and the lower Slave River are major spawning grounds for burbot and cisco, two species of Great Slave Lake fish. While these fish are of limited commercial value, burbot account for nearly 50% of the total domestic catch and cisco are important in the diet of lake trout and other predacious fish. In addition, the delta is a migratory corridor through which many commercially valuable species such as lake whitefish, inconnu, northern pike, and walleye pass on their way to and from spawning areas located farther upstream. It is likely that the aquatic invertebrates and the abundant numbers of small fish species in the delta make a significant contribution to the diets of these larger fish during their upstream and downstream migrations.

The Slave River Delta is of major economic importance to the residents of Fort Resolution. Fish have traditionally been an important source of food for the people of Fort Resolution and at one time accounted for more than 40% of the food supply. Lake whitefish and walleye still make up a significant portion of the diet and inconnu, goldeye, cisco, and burbot are used extensively as dog food.

Although there is no commercial fishing in the Slave River Delta, domestic fishing sites exist both on the delta and on the lower Slave River. Domestic fishing is carried out solely for the purpose of providing food for individuals, their families, and their dogs. Fishing intensity is determined by the size of the family and the number of dogs owned.

The muskrat is the animal resource of greatest cash value to the local residents. Hunting and trapping intensity is directly related to muskrat abundance and fur prices. During years when the muskrat populations and fur prices are high, increased numbers of local residents participate in the muskrat harvest.

Since the Slave River Delta is a part of a large staging area for migratory swans, geese, and ducks, waterfowl are also important to the people of Fort Resolution. Hunting of migratory birds by local residents is very intense and waterfowl alone account for almost 40% of the wild game consumed in Fort Resolution.

The harvesting of the Slave River Delta's natural resources has always been of paramount importance to the traditional life style of the people of Fort Resolution. Therefore, potential developments that may affect river regime could have a significant effect on the life style of the people of Fort Resolution.

2. Sensitivity to Environmental Change

The biological resources of the Slave River Delta are influenced by a wide variety of environmental factors. The most significant of these is the hydrologic regime. Indeed, the high productivity characteristic of the Slave River Delta is directly attributable to the natural fluctuations in the river systems. Since vegetation and wildlife patterns have developed in response to a fluctuating river regime, alterations in natural discharge patterns can be expected to alter biophysical conditions and thereby affect the biological resources.

The spring flood is considered to be the single most important hydrologic event in the delta (Figure A.II). This annual occurrence serves as the builder of deltaic structures, and supplier of nutrients and rooting media for vegetation. It is also instrumental in removing ice cover from the delta. The major contribution of the spring flood to the delta ecosystem is its role in maintaining delta plant communities at a highly productive early successional stage. Wetland ecosystems have a natural tendency to evolve toward less productive terrestrial ecosystems. However, annual flooding of delta lowlands in the spring neutralizes or even reverses this process by eliminating successionally advanced plants and creating favorable conditions for more primitive species. Two groups, Equisetum (horsetail) and the Salix-Equisetum (willow-horsetail) complex, are particularly well suited to withstand flooding and therefore flourish throughout the active delta. These two plant communities are the primary producers of the delta ecosystem and as such are the main sources of food for wildlife populations. In addition, the dense overgrowth of these plants provides excellent cover and protection for muskrats, fish, and waterfowl.

Figure A.11
Spring Flood
Slave River Delta

The volume of sediment carried by the Slave River is another feature of the hydrologic regime that affects the fish and wildlife resources of the delta. Deltas are dynamic systems which continuously grow downstream as they mature in the upstream areas. The older portions of the delta have developed structures typical of drier and more stable conditions while the young outer delta is characterized by siltbars and underwater levees extending outward from the river mouth. The deltaic structures of the outer delta along with extensive shoreline development provide rich and varied habitats for a large number of fish and wildlife species. Sediments deposited by the Slave River, as it enters Great Slave Lake, build up the existing structures, replace those removed by wind and wave erosion, and thereby ensure the continued growth of the outer delta.

The preceding discussion identifies two aspects of the hydrologic regime that are of importance to the fish and wildlife utilizing the delta. It is expected that reductions in flows, particularly during the spring flood, and decreases in the amount of sediment carried by the river would inflict a significant impact on the biological resources of the Slave River Delta.

The direct effects of an altered hydrologic regime on fish and wildlife populations of the Slave River Delta are difficult to determine because many other factors, beyond the scope of this study, influence their abundance, distribution, and behaviour. For example, waterfowl utilization of the area, in addition to being dependent on habitat availability, is affected by the size of the migrating population which in turn is dictated by conditions thousands of miles away. Similarly, muskrat populations are influenced by natural cyclic fluctuations in numbers and trapping effort, the latter being governed by fur prices and local weather conditions during the trapping season. However, it is possible to estimate the effects of changes in hydrologic regime on the biological resources of the delta based on the expected modifications in vegetation and landscape. The following discussion identifies the potential effects of altered flow regimes and decreased sediment loads on fish, muskrat, and migratory waterfowl populations in the Slave River Delta.

Although there do not appear to be large resident populations of major fish species in the delta, large numbers of lake whitefish, cisco, inconnu, pike, and walleye stop to forage in the delta during the late summer and fall en route to spawning areas farther upstream. Minor fish species such as lake chub, emerald shiner, and pearl dace, which are abundant throughout the delta, make up a large portion of the diet of larger fish. Since the minor fish species have demonstrated a marked preference for shallow well-vegetated habitats, and the existence of these is due to the effects of the spring flood, it is expected that reduction in flow or the absence of annual flooding will result in a decreased abundance of minor fish species throughout the delta. The subsequent loss of available food will alter the feeding habits of the major fish species and may ultimately result in changes in migratory and spawning patterns of fish utilizing the delta. Furthermore, low water levels would close off many of the minor side channels of the delta, making them inaccessible for use as rearing areas for young-of-the-year and limiting the number of channels available for upstream migration by the larger fish.

Muskrat populations are also dependent on the role played by the spring flood in maintaining certain vegetation species. As mentioned previously, horsetail (Equisetum fluviatile) is a major source of food for muskrats and the abundance of this plant is largely dependent on yearly flooding of delta lowlands. Since food availability is one of the factors limiting the size of muskrat populations, a decrease in muskrat numbers would result if reduction in spring flooding were to persist.

Other changes in water levels are also expected to affect muskrat populations adversely. The suitability of delta channels as overwintering habitat is predominantly due to an air space under the ice, formed when water levels decrease in the winter. This permits overwintering muskrats to forage for food under the ice in the frozen channels. If winter water levels increased or natural drawdowns ceased to occur, a decrease in muskrat overwintering survival would result. Conversely, if water depths were to decrease due to low autumn flows, many of the smaller channels inhabited by muskrats would freeze to the bottom and

a substantial portion of overwintering habitat would be lost.

Migratory waterfowl begin to utilize the Slave River Delta at the first sign of open water. The spring flood lifts, breaks, and removes ice from the delta, creating open sections of water much sooner than in surrounding areas. The absence of spring flooding could delay breakup in the delta for several weeks and result in the loss of suitable staging habitat for spring migrants. In addition, low water levels in the interlevee depressions during the spring flood would further reduce waterfowl nesting and feeding habitat. If low water levels persisted into the fall, additional aquatic and wetland habitats used for fall staging by migratory waterfowl would disappear. This continued reduction of good habitat could induce a major change in the migratory patterns of waterfowl using the delta.

The interlevee depressions of the outer delta are used extensively by whistling swans and geese. Since these landforms are maintained by deposition of river sediment, it is anticipated that reduction in sediment load could inhibit further development of deltaic structures and eventually the erosional forces of Great Slave Lake would reduce the size of the outer delta. A preferred staging habitat for swans and geese would disappear with the gradual shrinking of the outer delta.

Although it is evident that changes in the hydrologic regime would have potentially adverse effects on the fish and wildlife of the Slave River Delta, it should be noted that low flows, reduced spring flooding, and decreased sediment load have occasionally occurred naturally in the past and are likely to occur again in the future. Such changes have been withstood by the fish and wildlife populations without significant alterations to their numbers or habits, because natural disruptions to the hydrologic regime are generally short term. Therefore, changes in the hydrologic regime must persist over a relatively long time before their impact on the biological community of the Slave River Delta becomes evident.

3. Data Deficiencies

The Slave River Delta study provided useful information concerning the hydrology, fish, muskrats, and migratory birds of the delta. These studies were conducted over the relatively short period of three years; consequently, the results provide only general information on the biological resources and the hydrology of the delta. There are sufficient data to identify general trends in fish and wildlife populations and provide insight into the relationships between the biological resources and the hydrologic regime. Additional studies are required to be able to assess the impact of an altered hydrologic regime on the resources of the delta quantitatively. For example, study results indicate that an adverse effect on muskrat and small fish populations can be expected if delta water levels decreased during the fall. However, information identifying the magnitude of these adverse effects and how much water levels must decrease before these effects are observed is not available.

Areas of further work are suggested for each study component in Supplement 6 to this report and are briefly summarized below.

<u>Hydrology</u> A larger range of flows than those experienced during the three years of the study must be monitored to understand the hydrology of the delta properly. Studies of spring breakup and flow distribution should be continued for another five years or until a wide range of flows is experienced.

Fish Additional information concerning the major spawning areas and spawning seasons of lake whitefish, inconnu, pike, and walleye in the Slave River is needed. Information concerning lake whitefish and inconnu would be particularly useful because of their domestic and commercial value, and because large concentrations of these fish have been periodically observed at the base of the rapids at Fort Smith. Therefore, a tagging study in the vicinity of Fort Smith is required to accurately assess the importance of the Slave River to the fishery of Great Slave Lake.

Muskrats The variability in habitat selection by muskrats of the Slave Delta limits the usefulness of information obtained from short-term studies. Vulnerability and response of muskrats to changes in hydrologic regime cannot be properly assessed in only three years. Monitoring of habitat and muskrat population changes for a period of at least two population cycles is needed to document these responses. Further information regarding the yearly variations in numbers of muskrats overwintering in channel bank burrows is also needed.

Migratory Birds Further work is required to determine the importance of the Slave River Delta as an alternate waterfowl breeding habitat during the years when dry spring conditions are experienced in the prairie pothole region to the south. Additional fall and spring aerial surveys of staging habitats should be conducted periodically to establish the response of migratory birds to hydrologic conditions different from those experienced during the study.

Since this study was started, the Government of Alberta has initiated a major study program designed to establish the feasibility of developing the hydroelectric power potential of the Slave River. The results from the environmental portion of this program will provide further information regarding the biological resources of the Slave River Delta and will answer some of the residual questions from this study.

A Study Area
B Sand Dune Formation
C Climate
D Surface Hydrology
E Groundwater
F Vegetation
G Land Vertebrates
H Fish
I Archaeology
J System Relationships

Athabasca Sand Dunes in Saskatchewan

Appendix B

A three-year program of baseline studies in the Saskatchewan portion of the Athabasca Sand Dunes was undertaken in order to relate the ecology, landform, and associated resources of the sand dunes to the stream, lake, and groundwater hydrology of the area. It was considered timely to obtain this information in view of the rapid development taking place in northwestern Saskatchewan and adjacent parts of the Mackenzie River Basin. This appendix describes the area and the study results. A more complete discussion is found in Supplement 7 to this study report.

A. Study Area

The Athabasca Sand Dunes are located along the southern shore of Lake Athabasca in northwestern Saskatchewan and northeastern Alberta (Figure 2.21). They are the largest area of open sand at this latitude (59° North) in the world. The study area in Saskatchewan covers an area of 1200 km^2 (Figure B.1).

B. Sand Dune Formation

The sand dunes owe their existence to the underlying sandstone

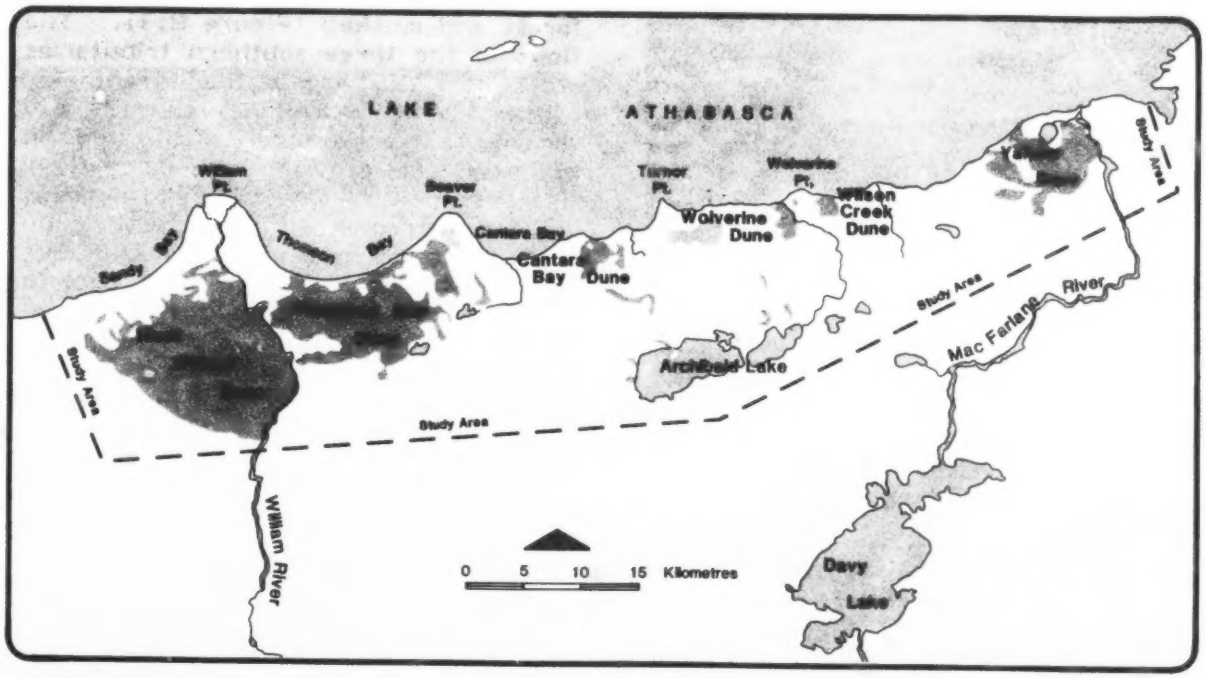


Figure B.1
Study Area
Athabasca Sand Dunes

bedrock of Precambrian age, known as the Athabasca Plain. Wave action and large quantities of moving water during glacial retreat 7000 to 10 000 years ago broke the structure of the sandstone surface down and produced unconsolidated sands. Thousands of years of wind action and deposition of vast amounts of sand along the southern shore of glacial Lake Athabasca by its southern tributaries resulted in the present sand dune landform (Figure B.2). The dominant dune shape in the area is parabolic. There are both active and stable sand dune complexes. The main factors influencing them are wind, water, and vegetation.

Figure B.2
Athabasca Sand Dunes

At present, the main influence on soil movement in the area is wind action, which easily erodes the unconsolidated sand particles. The sand dunes advance in a southeast direction, due to the prevailing northwesterly winds which sweep across Lake

Figure B.3
Advancing Sand Dunes

Athabasca and encroach on the adjacent forest and muskeg (Figure B.3). The flows of the three southern tributaries of Lake Athabasca (the Archibald, William, and MacFarlane Rivers) also contribute to sand movement through the processes of erosion and deposition. The presence of vegetation is the major stabilizing factor in the sand dune area. Also important is the presence of groundwater which acts as a force to hold the sand particles together and promotes the growth of vegetation. Thus, the present landform has been created and is maintained by a balance of opposing erosional and stabilizing forces.

C. Climate

The climate of the Athabasca Sand Dunes area is characterized by short cool summers and long cold winters. At Uranium City, on the north

Figure B.4
MacFarlane River

shore of Lake Athabasca, average daily temperatures vary from about -27°C in January to about 16°C in July. The average annual precipitation is approximately 35 cm, which is about the Saskatchewan average. However, precipitation in the sand dune area is more effective for promoting vegetation growth than it is in the south, due to a lower rate of evaporation resulting from the cooler average temperature. The prevailing northwesterly winds are strongest in the spring after snowmelt, thus enhancing the effectiveness of the wind as the major factor influencing erosion in the dune area.

D. Surface Hydrology

The main water bodies affecting the sand dune area are Lake Athabasca and the William, MacFarlane, and Archibald Rivers (Figures B.4 and B.5). The beach sands and the sand

Figure B.5
Archibald River

deposited by the three rivers are affected by changes in lake level and river flow.

The water level of Lake Athabasca is relatively stable with a maximum annual fluctuation of about one metre and a maximum historic fluctuation of about three metres. This relative lake stability is important in maintaining the balance of forces that regulate the sand dune landform.

When the lake level drops, the beach area is widened, more sand is exposed to wind action, and the newly exposed sand is blown into a new ridge which may become part of the active dunes south of the beach. In the William River area, 90 such ridges have developed over the past 2700 years (Figure B.6). The increased erosional capability associated with a lowering of lake levels is partially offset by the fact that lower levels on Lake Athabasca are usually accompanied by lower flows in the three main southern tributaries. Lower flows result in decreased erosional activity and less sand being deposited at the river mouths.

An increase in the level of Lake Athabasca decreases the amount of beach sand exposed to wind action and thus curtails sand dune formation. This is partially offset by associated high flows in the southern tributaries which increase erosion and result in more sand being deposited at the river mouths.

The actions that would lead to a lowering of water level in Lake Athabasca are upstream diversions, lowering of the outlet, and an increase in climatic aridity. Continued isostatic rebound may have some effects, but this is only in the very long term. Actions that could raise the lake level are damming at the outlet and increased runoff due to

Figure B.6
Beach Ridges

climatic or land-use changes. Other factors that could alter the hydrologic regime are changes in rates of water erosion and deposition which would affect the sediment load in the water. Increased sediments carried by the streams could result in a more rapid beach buildup, whereas a decrease in sediment load could result in a less rapid beach buildup.

E. Groundwater

Groundwater depths vary from zero, in lakes and muskeg areas, to 100 m in the high, bare dunes. The general groundwater system flows slowly to the north, discharging into Lake Athabasca through numerous small springs.

The stability of the water table is related to the stability of the sand dune area. A lowering of the water table decreases the stability of the sand dunes in the short term by decreasing the moisture level in the sand, and in the long term by causing a decrease in the vegetation cover. A rise in the water table causes a direct stabilization of the soil in the short term, and indirectly results in increased stability by promoting heavier vegetation cover in the long term.

A lower Lake Athabasca would allow wind movement of large volumes of dry sand now near the shore. A higher level would tend to stabilize these shores with a denser vegetation cover.

F. Vegetation

The vegetation of the sand dune area is basically boreal forest, except in the areas of open sand (Figure B.7). Common trees are jack pine, black and white spruce, birch, and tamarack. The uplands are dominated by jack pine; the low, boggy areas are characterized by black spruce, tamarack, and willow. The open sand areas have a limited vegetation cover consisting of low, shrubby plants such as juniper, dune grasses, and about 50 varieties of plants that are considered to be either rare or unique. Ten of these varieties are endemic to the dunes and gravel barrens south of Lake Athabasca and are found nowhere else in the world. Sandstone outcrops have a lichen cover.

Local ecological characteristics in the forest and open sand vegetation types are attributable to the sandy soil and the dune landforms. The advancing dunes sweep over, destroy, and replace forest vegetation with open sand, gravel barrens, and some cover of herbs and grasses. A vegetation succession follows: the herbs are replaced by shrubs and, eventually, by trees. The succession following forest fires is the normal one for the boreal forest of northwestern Saskatchewan. The forest type simply repeats itself over a number of years with approximately the same range of species.

The vegetation of the sand dune area, while vulnerable to advancing dunes, also acts as the main stabilizing influence in the dune landforms; this includes both active and stabilized areas. The stability of the vegetation cover, in turn, is dependent on an adequate groundwater supply. Thus, the vegetation-groundwater-landform complex is a system of balanced changes, highly vulnerable to manipulations of the hydrologic system.

Figure B.7
Open Sand Vegetation

G. Land Vertebrates

Species diversity and animal populations are low due to the simplicity of the ecosystem and generally low nutrient levels. The fauna of the Athabasca Sand Dunes are mostly typical of the boreal forest at that latitude, but low in numbers. Of special interest is the unusually high (or, at least, highly visible) population of the Canadian toad (Figure B.8).

The dominant mammals are moose and black bear, with commercial furbearers present in some numbers. Birds are present in good variety, but their numbers are not high. Known reptiles and amphibians are limited to two species of frogs (boreal chorus and leopard frogs) and the Canadian toad.

Figure B.8
Canadian Toad

H. Fish

The lower reaches of the William and MacFarlane Rivers support populations of commercial and sport fish such as whitefish, common suckers, and northern pike. The Archibald River contains no populations of major fish species, although arctic grayling spawn in the lower parts. Cantara, Royal, and East Archibald Lakes contain good populations of commercial and sport fish.

The rivers are important as spawning locations for the commercial and sport fish in Lake Athabasca. The lakes in particular contain important populations of sport fish. Changes in river flow and regime could lower these populations severely, disrupting or destroying an important economic base in the general area.

I. Archaeology

An archaeological survey of the Athabasca Sand Dunes was conducted to create a cultural sequence for the area. The goal was to determine where the people lived, what parts of the environment they used, and the extent of exploitation of the natural resources. In order to do this, an attempt was made to obtain a representative sample of archaeological information from the area.

The sand dunes appear to have been occupied by human hunters and gatherers from about 7500 years ago (Figure B.9) to the historic era, when a fur trading economy became dominant. The basic economy of the prehistoric peoples revolved around the caribou and, when caribou were not available, around moose, smaller game, and fish. The fur trade economy rapidly became part of the modern market system, with the people dependent on furbearers and to a large extent on the price of furs.

The archaeological survey together with information from known sites yielded the location of 59 sites. Most of the sites are within two kilometres of Lake Athabasca. All of the sites are prehistoric in age except one historic site, a trappers cabin near the MacFarlane River, which dates back to the 1930's.

Farther away from Lake Athabasca, the largest concentration of

Figure B.9
Indian Artifacts

sites occurs along the MacFarlane River in the eastern part of the sand dune area. The western part of the sand dunes away from the lake show very sparse utilization. Obviously, the emerging utilization pattern was heavily oriented toward Lake Athabasca and the MacFarlane River. As most of the sites are surface finds, very little can be said about the life style of the people who used the materials found at the sites. However, it is reasonable to conclude that they were hunters and gatherers.

The survey methodology involved a search of eroded areas near the lakes and rivers, and the systematic investigation of transects across the dune area, including vegetated and bare parts. Thus, it is safe to conclude that the settlement and utilization pattern indicated by the site distribution is reasonably accurate.

As most of the archaeological sites are near Lake Athabasca and the MacFarlane River, any manipulation that would significantly raise the water level of either of these two water bodies would result in the destruction of important historic resources. Lowered lake levels, on the other hand, could result in increased wind erosion which also would destroy sites and information.

J. System Relationships

Three ecosystem types exist within the Athabasca Sand Dunes area in Saskatchewan: uplands, lowlands, and aquatic. Upland ecosystems include active dune areas, stabilized dunes, gravel plains, and flat, sandy areas with forest cover. Lowland ecosystems include bogs, fens, lakeshores, and riparian areas. Aquatic ecosystems include lakes and rivers.

The active dunes are unstable, with a sparse cover of relatively rare plants and with few animal resources. The instability is due to an uneasy equilibrium between the combined erosive actions of wind and flowing water on the one hand and the stabilizing actions of groundwater and vegetation on the other hand. An increase in the erosive forces tends to increase the amount of open sand, and an increase in the stabilizing forces tends to increase the vegetation cover to the detriment of the open areas.

Although uninhabited, the sand dunes have been and are economically important to traditional hunters because of the variety and concentrations of terrestrial and aquatic animal life. However, the dunes contain few other economic resources. Even historic resources are limited to infrequent hunting campsites.

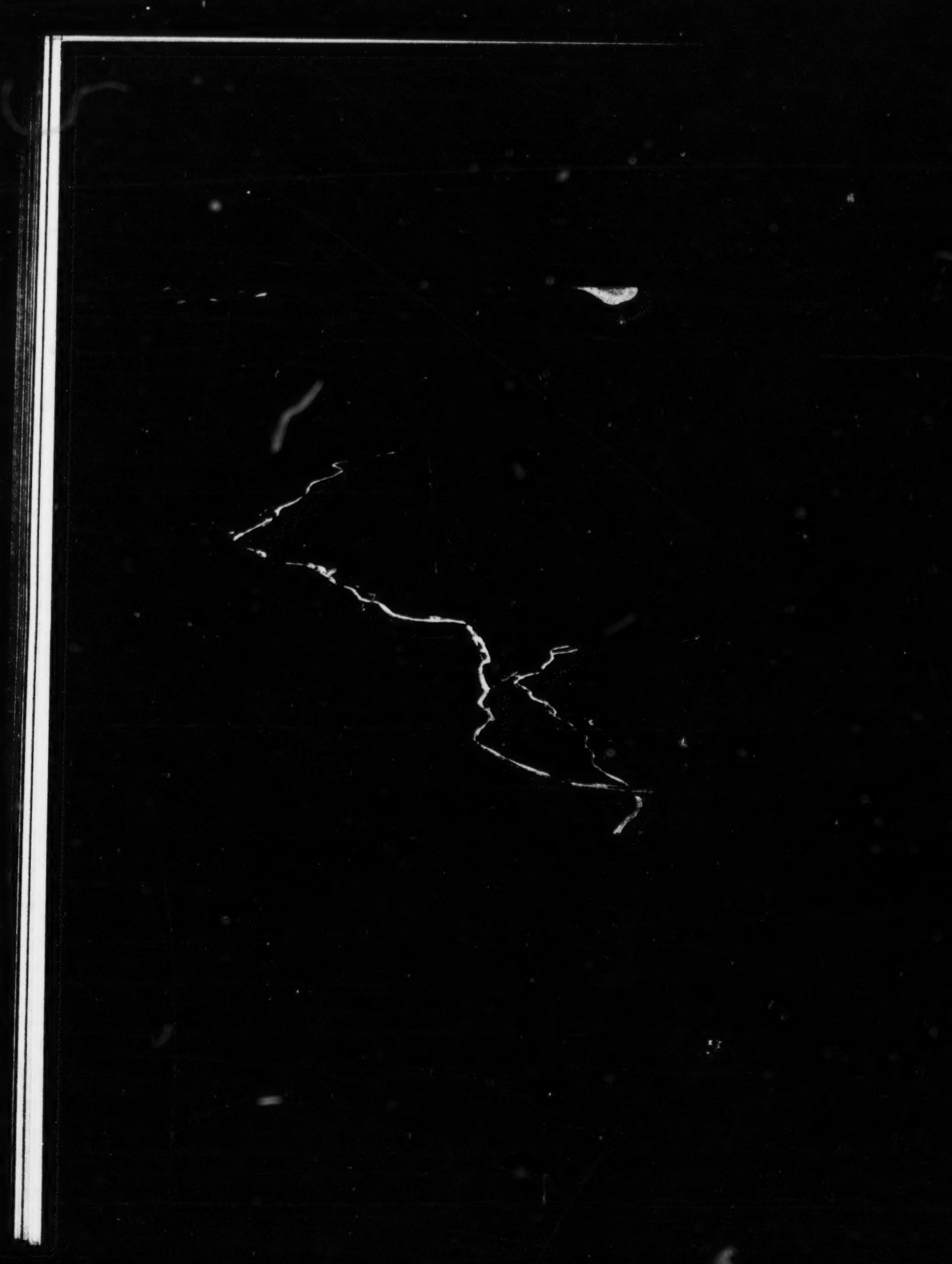
Due to the unstable nature of the light, sandy soils, the sand dunes are highly sensitive to disturbance, including manipulation of the hydrologic system. A lowering of the water table would result in increased dune movement by wind due to more loose, dry sand and to subsequent reduction in vegetation cover. On the other hand, a raising of the water table would result in a higher stabilization rate and more forest cover. Either way, the unique nature of the present sand dunes environment would be altered.

If the water level in Lake Athabasca were raised, the dune and aquatic ecosystems would receive the greatest impact: the bogs and other wetland areas would expand and active areas would tend to stabilize more rapidly. Lowering the lake level would result in more severe environmental changes: dune activity would increase, loss of vegetation cover would occur, and the wetland areas would shrink.

Decreased or increased flow rates in the rivers would result in some destabilization due to more dry sand or to an increased sediment load in moving water, respectively. Changes in the timing of flow would result in changes in fish populations in the rivers and lakes.

Roads, barge terminals, construction, and recreational activities frequently associated with water-based developments can have environmental effects. The Athabasca Sand Dunes are ecologically too fragile to withstand such pressure, even on a minimal basis, unless the activities are restricted to small, specific locations. Human activity in the area increases the risk of fire and the introduction of exotic species.

The Athabasca Sand Dunes are an area with beautiful, pristine beaches, dunes, and forests, relatively abundant wildlife, and unique plant varieties, all of which are in delicate equilibrium between the forces leading to erosion and those leading to stability. A small change in one of these factors could have significant effects on the landform and its ecological system, including changes in water levels and flows. Thus, the present sand dune area can tolerate little change in its associated hydrologic regime.



A Description of Daily Model
B Model Segments
C Constraints on Model's Use
D Summary

Computer Model of the River System

Appendix C

The size and complexity of the Mackenzie River Basin, its large development potential, and its inter-jurisdictional nature require a capability for computing the effects of new developments or changes in the operation of existing developments on water flows throughout the system. A "model," using formulas and calculations representing the water flow down the river, must be developed. This is almost unthinkable without the help of an electronic computer. As with any model, be it an architect's model of a house or a hobbyist's model of a boat or airplane, the goal is to make the model represent reality as closely as possible.

A. Description of Daily Model

The model developed for the Mackenzie River Basin is a mathematical representation of the flows and water levels of the main tributaries of the Mackenzie River System. It is called a "daily routing model" because it uses the recorded daily mean water discharges and water elevations at key points in the basin to describe the hydrology of the Mackenzie River and its main tributaries. It simulates the flow-routing effect of the river channels and lakes on the downstream movement of water through the river system (Figure C.1).

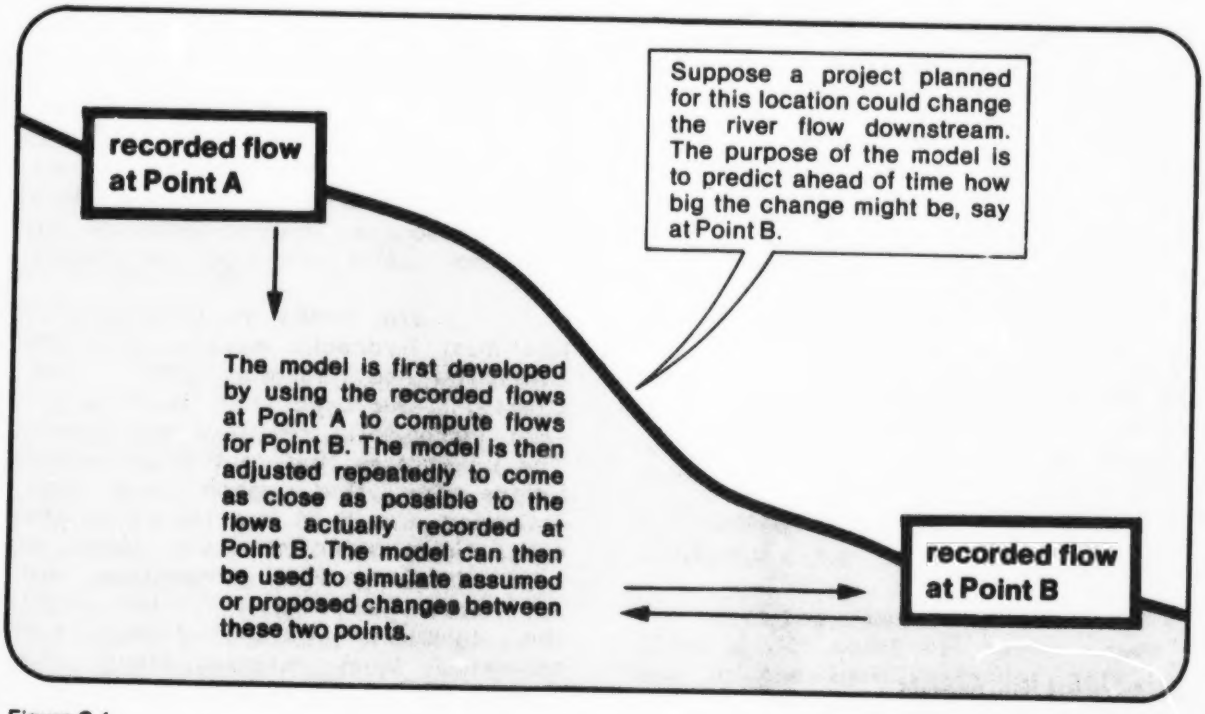

recorded flow at Point A
Suppose a project planned for this location could change the river flow downstream. The purpose of the model is to predict ahead of time how big the change might be, say at Point B.
The model is first developed by using the recorded flows at Point A to compute flows for Point B. The model is then adjusted repeatedly to come as close as possible to the flows actually recorded at Point B. The model can then be used to simulate assumed or proposed changes between these two points.
recorded flow at Point B

Figure C.1
Model Concept

The model represents the river flows as a series of daily mean discharges, one value per day for each station in the model. All flow calculations are based on those daily discharges. Water level - discharge relations are required wherever water elevations are computed, and storage-elevation relationships are required for all lakes and reservoirs. The operating rules or operating discharges for any reservoir or similar water resource development being tested are also a necessary input to the model. Given the above inputs, the model simulates the hydrologic conditions that would occur in the river if a development were in existence. For example, it can determine the detailed effects of projects on peak flows, minimum flows, and rising and falling water levels downstream. Similar models have been used in other studies of river regulation (e.g. the Columbia River in both Canada and the United States), major hydro projects, diversions, and flood control (e.g. Fraser River). The British Columbia Hydro and Power Authority is currently using the Liard River and Mackenzie River portions of this model in studies of proposed Liard River hydropower projects.

To test the effects of a proposed development a reference set of data is selected, usually a period of gauged flows, for a particular study period. The model computes the flows under an altered state of development on the river. The computed flows are then compared with the reference data to show the effects of the development under various operating rules.

B. Model Segments

The model covers only the major tributaries of the Mackenzie system and does not go upstream of the W.A.C. Bennett Dam on the Peace River, Hinton on the Athabasca River, and the Frances River junction on the Liard River. Additional tributaries can be added if necessary, provided hydrometric data are available for a reasonable period of record. Flows are routed downstream sequentially through one or more of the six segments making up the model (Figure C.2):

1. Athabasca River (Hinton to Lake Athabasca)
2. Peace River (downstream of Bennett Dam to Peace-Athabasca Delta)
3. Peace-Athabasca Delta and Lake Athabasca
4. Great Slave Lake
5. Liard River (Frances River to Fort Simpson)
6. Mackenzie River (Fort Providence to Arctic Red River).

All of the six segments are operated by using the SIMPAK computer program. The SIMPAK program is specifically designed to simulate the downstream flow routing effects, so that the changes in discharge and water level in a river due to various water resource developments at an upstream point can be calculated.

The "daily routing model," like most hydraulic models, must be calibrated to simulate the river closely. The calibration is done for each incremental reach of the river. The parameters that control the calculations for that reach are first estimated and then are tested in the calculations using observed flows as trial data. The parameters are adjusted in successive trials until the calculated routed flows plus estimated local inflows along the river match the observed downstream flows (Figure C.1).

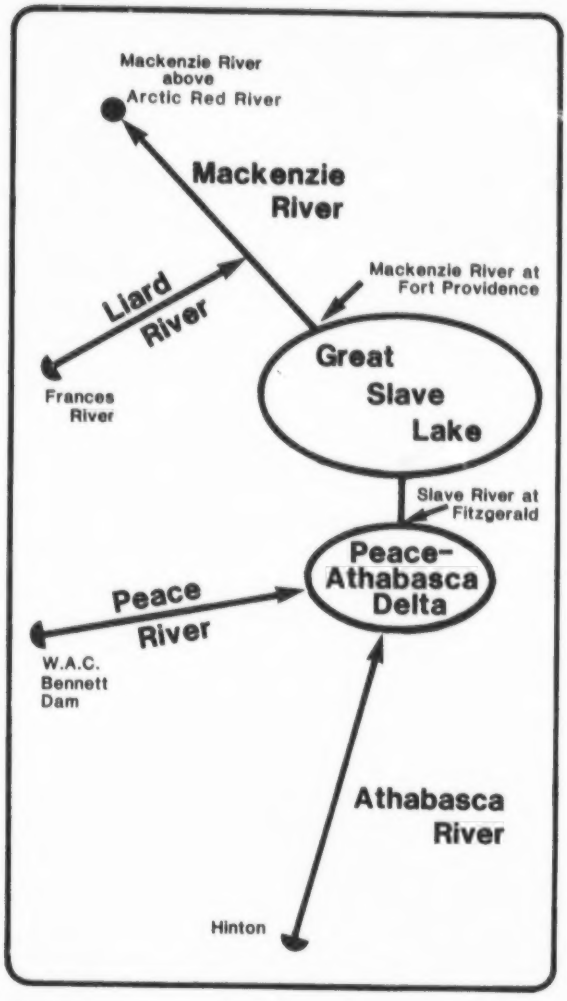


Figure C.2
Model Segments

Figure C.3 demonstrates the use of the model to determine the downstream effects of the W.A.C. Bennett Dam. The top hydrograph shows the present recorded flows for the Peace River at Taylor with the regulation from Williston Lake, and the computed natural flows with the effects of Williston Lake removed. The middle hydrograph shows present flows and natural flows for the Slave River at Fitzgerald, and the lower one shows present and natural flows for the Mackenzie River at Arctic Red River. These examples demonstrate the decreasing impact of the dam as one proceeds downstream. Using the model, multiple combinations of projects in different parts of the basin can be simulated and the impact on downstream flows can be shown in a convenient manner.

In addition to the SIMPAK-based daily model of the total river system, a "hydrodynamic model" has been developed by Alberta Environment and the Inland Waters Directorate, to route flows in a more precise manner through the complex Peace-Athabasca Delta. Deltas are difficult to simulate with SIMPAK because of their complex hydraulic character. For example, some channels in this delta experience a reversal of flows under spring flood conditions. The hydrodynamic model uses channel cross-sections and gradients to calculate flow directions, velocities, and total discharges. This model is capable of calculating discharges in all of the major delta channels, including those with man-made control structures. The hydrodynamic model is more expensive to operate than the daily model because of the complexity of the analysis used and the additional number of time increments. All calculations must be made with half-hour time increments rather than the daily increments used in the daily model. This model is necessary for detailed studies of the Peace-Athabasca Delta and Lake Athabasca levels.

C. Constraints on Model's Use

The calibration of many parts of the model was rather crude, due to the long distances between gauging stations and the lack of gauged inflows. When there are no observed flow records for use in

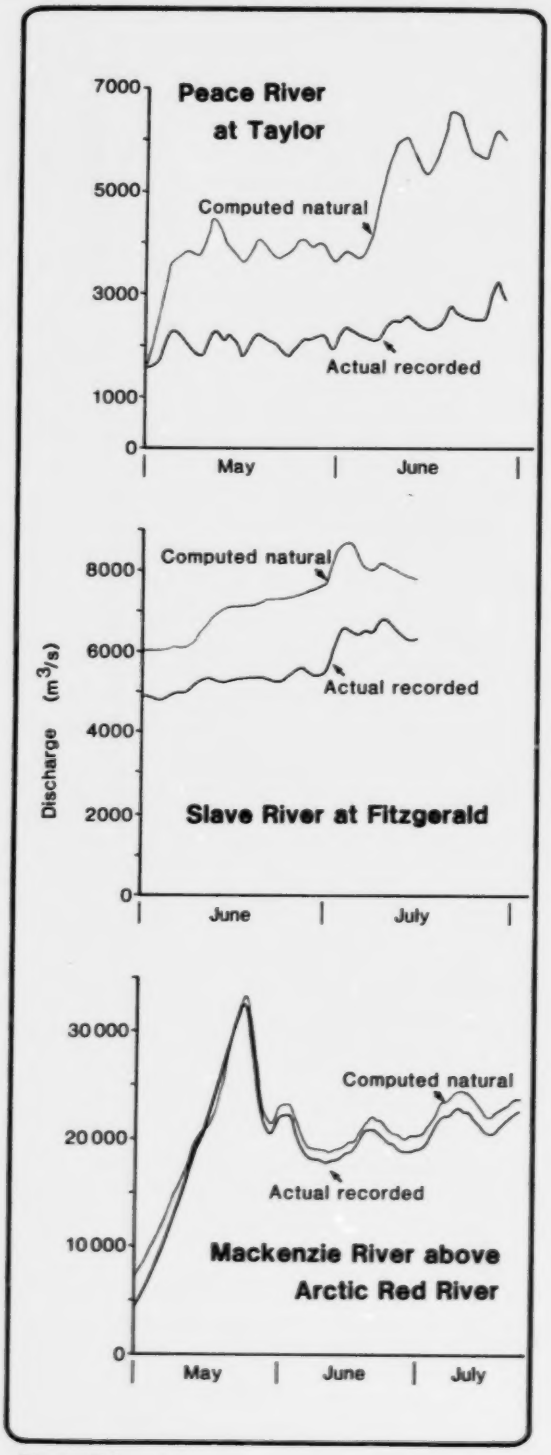


Figure C.3

Use of Model
showing effects of W. A. C.
Bennett Dam on flows downstream

tuning the model, the calibration must be made according to the best judgment of the hydrologist. It is intended that the Mackenzie Basin daily hydrologic model will be refined and the calibration improved as additional gauging stations are installed and as longer term records become available.

The model should be run only in studies where a proposed change in the river system is being tested against a known present condition or another computed project condition. For such studies a base set of records is required at all points representing the key hydrometric gauging station points along the river. Records missing at any of these stations should be filled in with estimated data before using the model. Missing data or grossly erroneous data will cause incorrect results in that portion of the model.

There are also complicating factors in the large lakes of the Mackenzie system due to wind setup, atmospheric pressure gradients, and difficulties in estimating evaporation, all of which may cause errors in the simulated lake levels. Wind setup, for example, introduces great uncertainties in calculating ungauged lateral inflows to Great Slave Lake. These effects on computed lake outflows are corrected at the next downstream gauge point, but the computed short-term level fluctuations in the lake will be erroneous.

Deltas introduce a complex set of hydraulic conditions due to the multitude of channels and the shifting division of flows among these channels. To define these shifting flow relationships through a calibration procedure requires a great number of detailed hydrometric measurements. In the absence of definitions for the many interconnected flow relationships it is necessary to use a hydrodynamic model that computes flows and elevations

from channel cross-section and water level gradient data. This has been deemed necessary for studies of the Peace-Athabasca Delta. The daily model of the Peace-Athabasca Delta can be used for rough estimates of the routing effects into and out of Lake Athabasca. The daily model will not produce accurate discharges out of Lake Athabasca during the two weeks each year of rapidly changing flows in the delta, and it will not produce the distribution of flows through all the individual channels of the delta.

The present daily model terminates at the entrance to the large and complex Mackenzie River Delta. A hydrodynamic model rather than a SIMPAK-based model will be necessary to study the hydrology of the Mackenzie River Delta adequately.

D. Summary

The Mackenzie River Basin daily hydrologic model can be used to simulate the downstream hydrologic effects of water resource developments where baseline data of satisfactory quality are available. A user manual with instructions for operating the model is contained in Supplement 8 to this report. The model will be updated as the period of record is extended and as additional hydrometric stations are added to the present network.

A Mackenzie River Basin Committee

B Study Agreement

C Study Organization

D Mackenzie River Basin Task Force

E Contractors and Advisory Groups

Study Program Documents

Appendix D

A. Mackenzie River Basin Committee

History

The idea of a committee to provide liaison and information exchange on Mackenzie River Basin activities was conceived during an intergovernmental seminar on the Mackenzie Basin attended by officials of the Governments of Canada, Alberta, British Columbia, Saskatchewan and the Yukon and Northwest Territories.

Prompted by the concern of the Council of the Northwest Territories over future basin development, some 40 delegates met at Inuvik in June 1972 to focus attention on the Mackenzie River Basin and specifically to assess the need for joint intergovernmental action and consider appropriate courses of action. The recommendations are published in the Proceedings of the Seminar. There was a consensus that the immediate concerns would best be met through the establishment of an intergovernmental liaison committee, as a vehicle for data and information exchange not only on investigatory and research matters but, perhaps most important, on intended developments within the basin.

The Mackenzie Basin Intergovernmental Liaison Committee was subsequently formed, following an exchange of letters between the federal Minister of the Environment and the Ministers of the participating governments, and the Committee's first meeting took place in Yellowknife on January 16, 1973. The Committee met nine times and issued three annual reports.

Federal and provincial Ministers met in 1977 to sign *Memorandum of Understanding Respecting the Water Resources of the Mackenzie River Basin* and reconstituted the Mackenzie Basin Intergovernmental Liaison Committee as the "Mackenzie River Basin Committee". The Ministers defined a broader role for the Committee, recognized the Northwest Territories and the Yukon Territory as full members of the Committee and subsequently signed the Study Agreement which enabled this study to be carried out. This Committee met nine times since being reconstituted and issued three annual reports.

Terms of Reference

Memorandum of Understanding

1. The Mackenzie River Basin Committee was established pursuant to the Memorandum of Understanding signed by Ministers representing British Columbia, Alberta, Saskatchewan and Canada on May 31, 1977.

Membership

2. The Mackenzie River Basin Committee is composed of senior officials of agencies of governments having jurisdiction within part or all of the Mackenzie River Basin.

Representation

3. The Committee shall consist of a maximum of twelve members, with no more than two members representing each of the Provinces of British Columbia, Alberta, and Saskatchewan, and not more than six members representing Canada.

4. Canada's membership will consist of one representative each of the Northwest Territories, the Yukon Territory, the Federal Department of Indian Affairs and Northern Development and the Federal Ministry of Transport, and two representatives of Environment Canada.

5. Members will be appointed by their respective Ministers, and any changes are to be communicated to the Minister, Federal Department of the Environment.

6. Each member shall appoint an alternate to act on his behalf.

Information Exchange

7. The Committee is to function as a vehicle for the exchange of information on studies and investigations pertaining to water and related resources, as well as providing information on intended developments in the Mackenzie River Basin within the jurisdiction of each Party.

Table D.1

MACKENZIE BASIN INTERGOVERNMENTAL LIAISON COMMITTEE (1972-1977)
MACKENZIE RIVER BASIN COMMITTEE (1977-)

Chairmen

Dr. A. T. Prince	1972-1974
J. P. Bruce	1974-1978
N. H. James	1978-1979
R. E. Bailey	1979-1980
G. E. Simmons	1980-1981
S. R. Blackwell	1981-

MEMBERS

Environment Canada

Dr. A. T. Prince	1972-1974
J. P. Bruce	1974-1978
E. F. Durrant	1974-1975
Dr. A. H. Macpherson	1975-
N. H. James	1978-

Indian Affairs and Northern Development

B. Yates	1972-1973
F. J. Joyce	1973-1975
M. J. Ruel	1975-1978
A. H. Jones	1978-

Transport Canada

R. H. Smith	1972-
D. E. Evans	1972-1976

Government of the Northwest Territories

A. Gordon	1976-1978
R. Creery	1978-1979
D. Billing	1979-

Government of the Yukon Territory

W. A. Bilawich	1977-1978
R. Morley Christie	1978-1980
M. Hawkes	1980-

Alberta

Dr. E. E. Ballantyne	1972-1978
R. E. Bailey	1972-
W. Solodzuk	1978-

British Columbia

B. E. Marr	1972-
G. E. Simmons	1979-81

Saskatchewan

G. C. Mitchell	1972-1980
• S. R. Blackwell	1972-
G. D. Koshinsky	1974-1976
M. O. L'Heureux	1977-1979
• Dr. A. R. Murray	1977-
R. L. Purdie	1979-
R. L. Carter	1980-

OBSERVERS

E. M. Clark, Environment Canada	1972-
P. Livingston	1975-1977
C. D. Forbes, Public Works Canada	1977-
A. G. Redshaw, Indian Affairs and Northern Development	1978-
W. A. Bilawich, Government of the Yukon Territory	1975-1977
D. Coombs	1976-1977
J. E. Lanigan	1977-1979
Francie Harle, Alberta Department of Intergovernmental Affairs	1979-
D. Patriquin	1974-1975
J. A. Bergasse	1975-1976
A. Gordon, Government of the Northwest Territories	1976-1977

• Alternates

Secretary

Environment Canada

J. G. M. Parkes	1972-1973
E. M. Nicolson	1973-1974
H. G. Mills	1974-1976
Hans Foerstel	1976-

The Committee acknowledges the participation and assistance of many other individuals not named here.

Studies and Investigations

8. The committee shall investigate, report and recommend to the Ministers upon:

   (a) the studies and investigations respecting water and related resources of the Basin that may be desirable,

   (b) the sequence in which studies and investigations should be carried out, and

   (c) with respect to each study and investigation,

      (i) the estimated cost thereof, and

      (ii) the estimated time needed for its completion.

Agreements and Management

9. The Committee shall recommend the undertaking of any studies or investigations and prepare agreements, subject to the approval of the Parties involved.

10. Cost-sharing shall be governed by the subject and area of study, and responsibilities of the respective governments.

Chairman

11. The chairman shall be appointed annually, by vote of the Committee, and shall not hold office longer than three years.

Secretary

12. The Secretary shall be supplied by the Federal Department of the Environment.

13. The Secretary shall keep the minutes of meetings and keep records of all committee business.

Observers

14. A Minister signatory to the Memorandum of Understanding may appoint official observers.

Annual Plan

15. The Committee shall submit to the Ministers an annual work plan and budget for their approval.

16. The Committee shall prepare an annual report for presentation to the Ministers at the end of each fiscal year, for subsequent release to the public.

Meetings

17. The Committee shall meet at least once a year, varying the location of meetings as agreed among the parties.

   (b) Any eight members or their alternates shall be a quorum, providing that at least two provinces are represented.

   (c) Each Party shall defray the costs of its representatives on the Committee.

Administration

18. The Committee shall:

   (a) establish appropriate financial procedures with respect to the work to be done and costs to be shared.

   (b) where a study or investigation is to be carried out, review or cause to be reviewed the contract proposals received and make such decision as in its opinion is appropriate.

   (c) establish task forces and subcommittees and determine the duties and terms of reference, as appropriate.

Other Duties

19. The Committee shall carry out such other related duties as the Ministers may request.

B. Study Agreement

AN AGREEMENT RESPECTING FEDERAL-PROVINCIAL STUDIES AND INVESTIGATIONS OF THE WATER RESOURCES IN THE MACKENZIE RIVER BASIN

THIS AGREEMENT made this first day of April, 1978

BETWEEN:

THE GOVERNMENT OF CANADA
hereinafter referred to as "Canada"

AND

THE GOVERNMENT OF THE PROVINCE OF BRITISH COLUMBIA
hereinafter referred to as "British Columbia"

AND

THE GOVERNMENT OF THE PROVINCE OF ALBERTA
hereinafter referred to as "Alberta"

AND

THE GOVERNMENT OF THE PROVINCE OF SASKATCHEWAN
hereinafter referred to as "Saskatchewan"

WHEREAS the Parties have signed a *Memorandum of Understanding Respecting the Water Resources of the Mackenzie River Basin,* dated May 31, 1977, a copy of which marked "Schedule A" is attached: and

WHEREAS the Parties have agreed to undertake studies designed to increase their understanding of the water and related resources of the Mackenzie River Basin, in order to facilitate future co-operation in planning and management for the best use of these resources; and

WHEREAS by Order in Council P.C. 1978-2/1354 made the 20th day of April 1978 pursuant to the *Canada Water Act* and the *Northern Inland Waters Act,* the Governor in Council has authorized the Minister of Environment for Canada, the Minister of Indian Affairs and Northern Development for Canada, and the Minister of Transport for Canada to execute this Agreement on behalf of Canada; and

WHEREAS by Order in Council No. 417/78 made the 4th day of April 1978 pursuant to the *Department of the Environment Act,* the Lieutenant Governor in Council has authorized the Minister of the Environment to execute this Agreement on behalf of Alberta; and

WHEREAS by order in Council No. O.C. 1021 made the 27th day of April 1978 pursuant to the *Canada-British Columbia Joint Development Act,* the Lieutenant Governor in Council has authorized the Minister of the Environment to execute this Agreement on behalf of British Columbia; and

WHEREAS by Order in Council No. 552/78 made the 11th day of April 1978 pursuant to the *Water Resources Management Act,* 1972, the Lieutenant Governor in Council has authorized the Minister of the Environment to execute this Agreement on behalf of Saskatchewan;

NOW THEREFORE THE PARTIES HAVE AGREED AS FOLLOWS:

DEFINITIONS

1. In this Agreement,

"Basin" means the drainage basin of the Mackenzie River and its tributaries;

"Committee" means the Mackenzie River Basin Committee, which was established by the Memorandum of Understanding referred to above (Shedule A hereto);

"fiscal year" means a period commencing on April 1, and ending on March 31 of the following year;

"Ministers" means

a) for Canada, the Minister of Environment, the Minister of Indian Affairs and Northern Development, and the Minister of Transport;

b) for British Columbia, the Minister of the Environment;

c) for Alberta, the Minister of the Environment, and the Minister of Federal and Intergovernmental Affairs; and

d) for Saskatchewan, the Minister of the Environment;

"related resources" means all flora, fauna, fish habitats and other natural features, the presence or existence of which in the Basin is dependent upon the river system of the Basin.

PROGRAM OF WORK

2. The Committee shall submit to the Ministers for their approval, for the first fiscal year of this Agreement and in advance of every subsequent fiscal year of this Agreement until investigations are complete:

   (a) a work plan setting out the particular studies and investigations listed in Schedule B of this Agreement, that the Committee recommends to be undertaken in such year; and

   (b) an annual budget.

3. The Ministers may, by mutual agreement, amend an annual work plan and budget submitted by the Committee pursuant to Article 2

   (a) before approving it; or

   (b) at any time during the year for which it has been approved, to the extent permitted by the appropriations therefore.

4. The Committee shall carry out or cause to be carried out all the studies and investigations generally described in Schedule B.

5. The Committee shall, with respect to annual work plans approved by the Ministers, monitor the work and ensure that the work is performed in accordance with the terms of reference.

6. The Committee shall prepare:

   (a) annual reports on the progress of the study program (Schedule B) for presentation to the Ministers and for subsequent release to the public; and

   (b) a comprehensive report on the study program for presentation to the Ministers by the thirty-first day of August, 1981, and for subsequent release to the public.

7. Where work is carried out by a third party, the Party which entered into the contract shall conduct such monitoring and review; in addition to that carried out by the Committee pursuant to Article 5, as is necessary to ensure that the contract is performed in accordance with the terms of reference.

8. No work to be carried out pursuant to this Agreement shall be commenced before monies therefore have been appropriated by the Parties.

FINANCES

9. The costs of the study program described in Schedule B, including the costs of study coordination, management and reports, shall be shared by the Parties in the proportions shown in Column A but the sum payable by each Party to this Agreement in respect of all such costs shall not exceed the amount shown in column B:

	Column A Share of Costs	Column B Maximum Amount Payable
Canada		
Environment Canada and Department of Transport	50%	$ 800,000
Department of Indian Affairs and Northern Development (Yukon Territory & Northwest Territories)	26%	416,000
Alberta	13%	208,000
British Columbia	8%	128,000
Saskatchewan	3%	48,000
Total	100%	$1,600,000

10. Each Party shall bear the entire costs of the salary and travelling and related expenses of:

    (a) each of its members on the Committee; and

    (b) any other employee who, although engaged in an activity hereunder, does not have a specified portion of his day, week, month or year assigned exclusively to the carrying out of this Agreement or work hereunder;

    and such costs shall not be included in calculating the amounts payable as stipulated under Article 9.

11. (1) Canada shall, with respect to the costs to which Article 9 is applicable;

    (a) pay such costs as they come due; and

    (b) where the cost is incurred by a Province, reimburse the Province upon submission of the claim in a mutually agreed manner and form.

    (2) Each participating Province shall pay to Canada that Province's share of expenditure made by Canada pursuant to this Agreement upon the submission of a claim in a mutually agreed manner and form by Canada, certified by a senior officer of Canada.

12. (1) Each Party shall maintain adequate documentation and records of the costs that are to be shared pursuant to Article 9 and which are incurred by it and shall, upon request, make available such documentation and records for examination by auditors of any other Party sharing the costs.

(2) An audit of its expenditures shall be made by each Party at the end of each fiscal year. Any discrepancy disclosed by audit shall be promptly adjusted among Parties.

GENERAL

13. (1) This Agreement shall take effect on the first day of April, 1978 and shall terminate on the thirty-first day of August, 1981.

(2) The provision of this Agreement respecting the payment of costs that are to be shared by the Parties under this Agreement shall remain in effect until the thirty-first day of March, 1982.

(3) Any material, equipment or property:

(a) the cost of which was included in the costs of research, surveillance, or assessment shared by the Parties to this Agreement; and

(b) which is no longer needed for the purpose for which it was acquired,

shall revert to the Party responsible for it, at its depreciated cost, in accordance with the Income Tax Act capital allowance schedule. In the event that the Party opts not to acquire an asset, the asset should be disposed of in the manner authorized by the statutes of Canada respecting disposal of surplus Crown assets.

14. No member of the Parliament of Canada shall hold, enjoy, or be admitted to any share, part or benefit from this Agreement or any agreement, contract or benefit arising therefrom.

15. This Agreement may from time to time be reviewed by the Parties hereto and with the approval of the Governor in Council for Canada and the Lieutenant Governor in Council for the Provinces of Alberta, British Columbia and Saskatchewan, may be revised.

IN WITNESS WHEREOF the Minister of Environment, the Minister of Indian Affairs and Northern Development, and the Minister of Transport have hereunto set their hands on behalf of Canada, and the Minister of the Environment (British Columbia) has hereunto set his hand on behalf of British Columbia, the Minister of the Environment (Saskatchewan) has hereunto set his hand on behalf of Saskatchewan, and the Minister of the Environment (Alberta) has hereunto set his hand on behalf of Alberta.

In the presence of:
(Sgd.) Romeo LeBlanc
Minister of Environment (Canada)

(Sgd.) W. Allmand
Minister of Indian Affairs and
Northern Development (Canada)

(Sgd.) O. E. Lang
Minister of Transport (Canada)

(Sgd.) J. A. Nielsen
Minister of the Environment
(The Province of British Columbia)

(Sgd.) Neil E. Byers
Minister of the Environment
(The Province of Saskatchewan)

(Sgd.) D. J. Russell
Minister of the Environment
(The Province of Alberta)

This agreement is hereby approved and ratified as a binding Intergovernmental Agreement of the Government of Alberta as evidenced by the signature of the Minister of Federal and Intergovernmental Affairs.

(Sgd.) Louis D. Hyndman
Minister of Federal and Intergovernmental
Affairs (Alberta)

Schedule A

Water Resources of the Mackenzie River Basin

The exchange of data and information on the water resources of the Mackenzie River Basin has been the subject of several meetings of the Mackenzie Basin Intergovernmental Liaison Committee established in 1972 to co-ordinate the exchange.

In the spirit of mutual co-operation, we the undersigned agree to support the arrangements proposed in the attached document entitled "Memorandum of Understanding Respecting the Water Resources of the Mackenzie River Basin".

In the presence of:
(Sgd.) Romeo LeBlanc
Minister of Environment (Canada)

(Sgd.) W. Allmand
Minister of Indian Affairs and
Northern Development (Canada)

(Sgd.) O. E. Lang
Minister of Transport (Canada)

(Sgd.) J. A. Nielsen
Minister of the Environment
(The Province of British Columbia)

(Sgd.) Neil E. Byers
Minister of the Environment
(The Province of Saskatchewan)

(Sgd.) D. J. Russell
Minister of the Environment
(The Province of Alberta)

(Sgd.) Louis D. Hyndman
Minister of Federal and
Intergovernmental Affairs (Alberta)

MEMORANDUM OF UNDERSTANDING RESPECTING THE WATER RESOURCES OF THE MACKENZIE RIVER BASIN

THE MINISTERS RECOGNIZE THAT:

The drainage basin for the Mackenzie River extends geographically and jurisdictionally across parts of the Yukon and Northwest Territories and the Provinces of British Columbia, Alberta and Saskatchewan.

The Basin is rich in renewable and non-renewable resources and its waterways constitute a major transportation route to the Western Arctic.

Water is an essential factor in the maintenance of important productive ecosystems along the river systems of the Mackenzie Basin, particularly in the Mackenzie Delta, Peace-Athabasca Delta and Slave Delta areas.

Major developments may affect the quality, flows and levels of the waters in the Basin, and these effects may extend beyond the province or territory in which a development is situated.

THE MINISTERS CONCUR ON THE FOLLOWING MATTERS:

1. Committee Membership — The Mackenzie Basin Intergovernmental Liaison Committee is hereby re-established as the Mackenzie River Basin Committee. The Committee shall consist of a maximum of twelve members, consisting of not more than two members representing each of the Provinces of British Columbia, Alberta and Saskatchewan and not more than six members representing Canada.

2. Information Exchange — The Ministers may, through the Committee, exchange with each other data on studies and investigations undertaken or to be undertaken by their respective jurisdictions respecting the water and related resources of the Basin.

3. Studies and Investigations — The Committee shall investigate and recommend to the Ministers upon:

   (a) the studies and investigations respecting water resouces of the Basin that may be desirable.

   (b) the sequence in which studies and investigations should be carried out, and

   (c) with respect to each study and investigation,
      (i) the estimated cost thereof, and
      (ii) the estimated time needed for its completion.

4. Agreements and Management — The undertaking of any or all of the inter-jurisdictional studies and investigations recommended to the Ministers by the Committee from time to time may be achieved through agreements negotiated by, and subject to the approval of, the specific governments involved.

5. Annual Work Plan — The Committee, with respect to the matters referred to in Sections 3 and 4 of this Memorandum of Understanding, shall also submit to the Ministers for their approval an annual work plan.

6. Cost-Sharing — There is no commitment for cost-sharing under this Memorandum of Understanding.

7. Termination — Participation in the arrangements described in this Memorandum of Understanding may be terminated by any government by serving two months' written notice to the other governments.

Schedule B

Mackenzie River Basin Program

INTRODUCTION

The tasks to be undertaken under the Agreement, their cost and the lead agencies are as described below. The annual work plans submitted by the Mackenzie River Basin Committee, pursuant to Article 2 of the Agreement, will constitute a more final description of each year of the Study Program.

1. PIPELINE DOCUMENTS REVIEW

Pipeline documents have been reviewed for the purpose of identifying useful new information relating to water resource management in the Mackenzie River Basin. Provision is made under this study program to follow up on this work in the first year, and delve into selected references and sources for particularly useful or promising information. The review will be completed in 1978-79.

Cost $20,000

Lead Agency Canada, Department of Indian Affairs and Northern Development (Ottawa)

2. INFORMATION EXCHANGE

A basic purpose of the Mackenzie River Basin Committee has been, and will continue to be, the exchange of information on the water and related resources of the Basin. It is proposed to continue and build upon two previous activities.

1. Documents relating to the water resources of the Mackenzie River Basin will be abstracted and entered into WATDOC computer reference system.
2. The Mackenzie Reference Binder will be updated.

Cost $45,000

Lead Agency Canada, Department of Environment, Inland Waters Directorate (Regina)

3. HYDROLOGIC SYSTEM

The study will provide a better understanding of the existing hydrologic system of the Mackenzie River Basin, including water quality and sedimentation. Such an understanding will assist in assessing the results of any changes in the hydrologic system which might result from potential developments.

A mathematical model of the hydrologic system will be developed to help determine, in future, the downsteam effects of developments. A detailed study will address itself to the planning and co-ordination of hydrometric and meteorological data networks in the Basin. The resulting knowledge of the hydrologic system will help in making decisions or deductions with respect to a variety of operations or fields of study, such as wildlife habitat, fish studies, floods, and river navigation.

Cost $259,000

Lead Agency Canada, Department of Environment, Inland Waters Directorate (Regina)

4. POTENTIALLY SENSITIVE AREAS

The objective of this component is to firmly identify those areas sensitive to changes in the hydrologic system, including changes in flow regime, sedimentation and water quality; and to initiate the development of a baseline data bank for future use in evaluating development proposals.

A. The Study will document existing information on a pre-determined, but not exclusive, list of important areas in the Mackenzie River Basin and include an inventory of the biologic, physical, hydrologic and historic resources of each sensitive area and their inter-relationships with the socio-economic activity of each area.

B.C.D. The main work under this component is the detailed study of three important sensitive areas (Slave River, Slave River Delta, Athabasca Sand Dunes) where baseline data are seriously deficient.

E. This is a socio-economic overview of the Mackenzie River Basin.

Component	Cost
A. Compilation of Existing Information	$ 40,000
B. Slave River Delta	518,000
C. Slave River	111,000
D. Athabasca Sand Dunes	72,000
E. Socio-economic Studies	60,000
	$801,000

Lead Agency

A. Canada, Department of Environment, Inland Waters Directorate (Regina)
B. Canada, Department of Indian Affairs and Northern Development (Yellowknife)
C. Alberta, Department of Environment (Edmonton)
D. Saskatchewan, Department of Environment (Regina)
E. Canada, Department of Indian Affairs and Northern Development (Ottawa)

5. Spring Flood

The study will consist of assessing the past and documenting current ice-caused flood events, recording ice movements and ice jams, and determining in a general way the sources, transportation and deposition of sediments.

The annual spring break-up is the major hydrologic event in the Mackenzie River Basin, and an understanding of this event is necessary to the assessment of any potential development which could cause its alteration. The study will concentrate on the Mackenzie River downsteam from Fort Simpson and the Liard River from its source to its mouth. The study will also encompass consideration of the spring floods on the Peace River at the town of Peace River and the Athabasca River at Fort McMurray, based upon existing information.

Cost $100,000

Lead Agency Canada, Department of Indian Affairs and Northern Development (Ottawa)

6. PUBLIC INFORMATION

A Public Information Program is required to inform the public in general and residents of the study area in particular about the Mackenzie River Basin Study Program. Establishing and maintaining liaison with local communities on study activities and field work will be particularly important. Two public information brochures will be produced, one on the Mackenzie River Basin and one about the Study Program.

Cost $60,000

Lead Agency Canada, Department of the Environment (Regina) — Information Brochures

Saskatchewan, Department of the Environment (Regina) — Athabasca Sand Dunes

Alberta, Department of the Environment (Edmonton) — Slave River

Canada, Department of Indian Affairs and Northern Development (Yellowknife) — Slave River Delta

Study Coordination — Management

The salary and expenses of the study co-ordinator, task force expenses (where charged by the Parties), and general program and Committee support will be borne by the study program.

Cost $150,000

Lead Agency Canada, Department of Environment, Inland Waters Directorate (Regina)

Report

A comprehensive report will be prepared in the spring and summer of 1981 on the study program, for review by the Ministers and subsequent publication.

Cost $30,000

Lead Agency Canada, Department of Environment, Inland Waters Directorate (Regina)

Contingencies

Provision is made for contingencies in each year of the study program to be allocated by the Mackenzie River Basin Committee according to needs and priorities during the program.

Cost $135,000

Lead Agency Not applicable.

7. ANNUAL BUDGETS

The budget for the three year program is a maximum of $1,600,000, cost-shared among three federal agencies and three provinces. Below is presented the firm budget for 1978-79 and "tentative budgets" for fiscal years 1979-82.

THOUSANDS OF DOLLARS

	1978-79	*1979-80*	*1980-81*	*1981-82*	*Total 1978-82*
1. Pipeline Documents Review	$ 20	—	—	—	$ 20
2. Information Exchange	15	*20*	*10*	—	45
3. Hydrologic Systems	80	*128*	*51*	—	259
4. Potentially Sensitive Areas					
A. Compilation of Existing Information	40	—	—	—	40
B. Slave River Delta	199	*176*	*143*	—	518
C. Slave River	14	*41*	*56*	—	111
D. Athabasca Sand Dunes	4	*34*	*34*	—	72
E. Socio-Economic	—	*30*	*30*	—	60
5. Spring Flood	20	*30*	*50*	—	100
6. Public Information	30	*15*	*15*	—	60
Study Coordination-Management	50	*40*	*40*	*20*	150
Report	—	—	—	*30*	30
Contingencies	28	*56*	*51*	—	135
	$500	*570*	*480*	*50*	$1,600

The Cost of the program is shared as follows:

		1978-79	*1979-80*	*1980-81*	*1981-82*	*Total 1978-82*
Canada						
Department of Environment and Department of Transport	50%	250,000*	*285,000*	*240,000*	*25,000*	800,000
Department of Indian Affairs and Northern Development	26%	130,000	*148,200*	*124,800*	*13,000*	416,000
British Columbia	8%	40,000	*45,600*	*38,400*	*4,00*	128,000
Alberta	13%	65,000	*74,100*	*62,400*	*6,500*	208,000
Saskatchewan	3%	15,000	*17,100*	*14,400*	*1,500*	48,000
	100%	500,000	*570,000*	*480,000*	*50,000*	1,600,000

* Includes Department of Transport contribution of $20,000 in 1978-79

Note
This is the overall budget reproduced from the original study agreement. Actual expenditures were about $1 350 000.

C. Study Organization

The Mackenzie River Basin Task Force, assisted by a Study Coordinator, was responsible for study management, under the general direction of the Mackenzie River Basin Committee (Figure D.1). Advisory groups assisted in the design of study components, and reviewed interim and final reports. The agency responsible for a contract provided the chairman for the advisory group. Contractors and advisory groups are listed in Section E of this appendix.

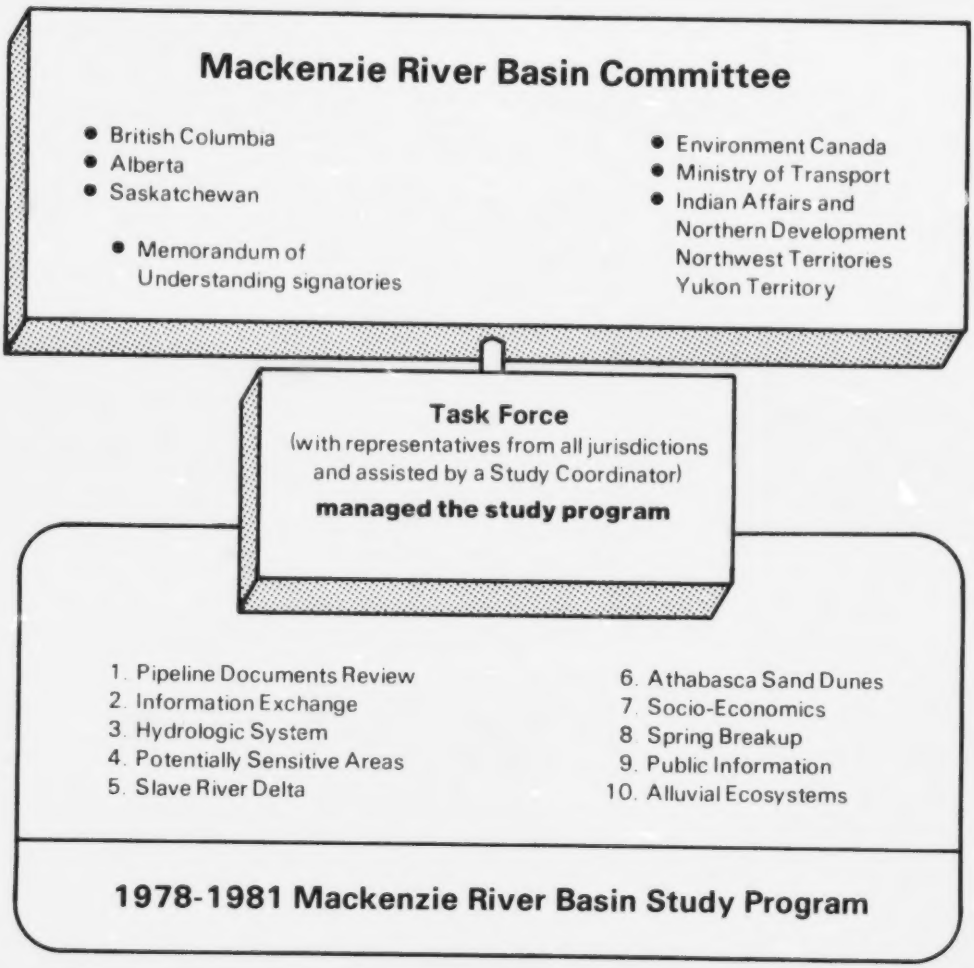


Figure D.1
Study Organization

D. Mackenzie River Basin Task Force

Terms of Reference

1. The Mackenzie River Basin Task Force, established by the Mackenzie River Basin Committee on September 27, 1977, will provide support to the Committee on all matters related to the Memorandum of Understanding, through such activities as:
   (a) Advice and recommendations on program development;
   (b) Management of programs as delegated by the Mackenzie River Basin Committee; and
   (c) Other related duties as the Mackenzie River Basin Committee may assign.
2. The Task Force will consist of a maximum of nine members and one secretary. Membership will be as follows: one member each representing the Provinces of Saskatchewan, Alberta, and British Columbia; one member from Environment Canada; one member each from the Governments of the Northwest Territories and the Yukon Territory; and three members from the Federal Department of Indian Affairs and Northern Development.
3. Members will be appointed by their respective governments or agencies. Any membership changes are to be communicated to the Chairman of the Mackenzie River Basin Committee by a member.
4. If a member is unable to attend, he may name an alternate to act on his behalf. On such an occasion, the alternate will enjoy full member status.
5. The Task Force Chairman will be appointed by the Mackenzie River Basin Committee, giving consideration to the recommendation of the Task Force. The Chairman will attend all meetings of the Mackenzie River Basin Committee and be prepared to report on Task Force activities to the Committee.
6. The Task Force Secretary will be provided by Environment Canada.
7. The Task Force will meet as required to discharge its responsibilities. The location of meetings will vary among the participating jurisdictions.
8. The expenses of each Task Force member will be the responsibility of his agency unless arrangements for such fundings are contained within a specific study agreement. As the Task Force has no direct funding capability the expenses for an advisor invited to a meeting by a Task Force member will be arranged between the Task Force member and the agency represented by the advisor.

Membership

H. Foerstel Chairman, 1977-present	Head, Planning Division Inland Waters Directorate Environment Canada Regina, Saskatchewan
H. T. Epp 1977-present	Resources Management Consultant Policy, Planning and Research Br. Saskatchewan Department of Environment Regina, Saskatchewan
G. D. Lewis Secretary 1977-present	Mackenzie River Basin Study Coordinator Water Planning & Management Branch Inland Waters Directorate Environment Canada Regina, Saskatchewan
R. B. Maclock 1981-present	Senior River Basin Planner, Northern Region Planning Division Alberta Environment Edmonton, Alberta
S. Metikosh 1980-present	Senior Aquatic Biologist Water Resources Division Northern Affairs Program Department of Indian Affairs and Northern Development Yellowknife, N. W. T.
A. R. D. Robertson 1977-present	Senior Hydraulic Engineer Aquatic Studies, Water Management Branch B.C. Ministry of Environment Victoria, British Columbia
B. Scott 1980-present	Coordinator, Science Programs Environmental Sciences Division Dept. of Renewable Resources Government of the Northwest Territories Yellowknife, N.W.T.
A. Waroway 1977-present	Head, Engineering and Planning Section Water Resources Division Northern Renewable Resources Program Department of Indian Affairs and Northern Development Ottawa, Ontario

W. G. Whitley 1978-present	Regional Manager Water Resources Branch Renewable Resources Department of Indian Affairs and Northern Development Whitehorse, Y.T.
L. Garinger 1977-78	Regional Manager Water Resources Branch Renewable Resources Department of Indian Affairs and Northern Development Whitehorse, Y.T.
R. A. Hale 1977-80	Regional Manager Water Resources Division Northern Affairs Program Department of Indian Affairs and Northern Development Yellowknife, N.W.T.
M. Hawkes 1978-79	Environmental Coordinator Fish and Wildlife Service Department of Natural & Cultural Affairs Government of the Northwest Territories Yellowknife, N.W.T.
J. Mackenzie 1977-78	Environmental Assessment Biologist Fish and Wildlife Service Department of Natural & Cultural Affairs Government of the Northwest Territories Yellowknife, N.W.T.
J. Simpson 1977-80	Senior River Basin Planner, Northern Region Planning Division Alberta Environment Edmonton, Alberta

E. Contractors and Advisory Groups

1. Contractors

- **Sensitive Areas Literature Review**

  Salix Enterprises Ltd., Cowley, Alberta
  Wm. Nielsen, Consultant, Calgary

- **Alluvial Ecosystems**

  Western Ecological Services Limited
  Victoria, British Columbia
  in association with
  Salix Enterprises Ltd., Cowley, Alberta

- **Spring Flood**

  National Hydrologic Institute
  Inland Waters Directorate
  Environment Canada, Ottawa

  M. Fox (Fluvial processes)
  Underwood McLellan Ltd., Winnipeg

- **Hydrometeorologic Network Design**

  Water Survey of Canada
  Inland Waters Directorate
  Environment Canada, Calgary

  Atmospheric Environment Service
  Environment Canada, Edmonton

  Water Quality Branch
  Inland Waters Directorate
  Environment Canada, Calgary and Ottawa

  Hydrocon Engineering Ltd.
  in association with
  Reid, Crowther & Partners Ltd., Calgary

  Water Survey of Canada
  Inland Waters Directorate
  Environment Canada, Regina
  (Supplement 4)

- **Slave River Delta**

  J. D. Mollard & Associates Ltd.
  Regina

  Water Survey of Canada
  Inland Waters Directorate
  Environment Canada, Calgary

  Aquatic Environments Ltd., Calgary

  Department of Geography
  University of Alberta, Edmonton

  Canadian Wildlife Service
  Environment Canada, Edmonton

  Ken Bodden
  Department of Geography
  University of Alberta, Edmonton

  Fish and Wildlife Service
  Department of Renewable Resources
  Government of the Northwest
  Territories, Yellowknife, N.W.T.

- **Athabasca Sand Dunes**

  Saskatchewan Research Council, Saskatoon

- **Daily Hydrologic Model**

  Inland Waters Directorate
  Environment Canada
  Water Planning and Management Branch
  Regina and Vancouver and
  Water Survey of Canada, Calgary

- **Information Exchange**

  Boreal Institute for Northern Studies
  University of Alberta, Edmonton and
  Water Documentation Center,
  Inland Waters Directorate
  Environment Canada, Ottawa

- **Other**

  Archtech Services Ltd., Inuvik, N.W.T.

  Outcrop Limited, Yellowknife, N.W.T.

  Weston Graham and Associates, Ottawa

  Underwood McLellan, Winnipeg

2. Sensitive Areas Literature Review Advisory Group

G. D. Lewis Chairman, 1978-1980	Coordinator Mackenzie River Basin Study Inland Waters Directorate Environment Canada, Regina
K. Ambrock 1978-1980	Wildlife Biologist Canadian Wildlife Service Environment Canada Edmonton, Alberta
L. Allison 1978-1980	Salix Enterprises Ltd. Cowley, Alberta
W. Nielsen 1978-1979	Calgary, Alberta

3. Alluvial Ecosystems Advisory Group

H. Foerstel Chairman, 1980-1981	Head, Planning Division Inland Waters Directorate Environment Canada, Regina
D. A. Blood 1980-1981	President D. A. Blood and Associates Lantzville, British Columbia
R. Kellerhals 1980-1981	President Kellerhals Engineering Services Ltd., Heriot Bay, British Columbia
S. Zoltai 1980-1981	Environmental Impact Assessment Project Leader, Northern Forestry Research Centre Canadian Forestry Service Edmonton

4. Spring Flood Advisory Group

A. Waroway Chairman, 1978-1981	Head, Engineering & Planning Section Water Resources Division Northern Renewable Resources Program Department of Indian Affairs and Northern Development, Ottawa
K. Davies 1978-1981	Northern Operations Engineer Water Survey of Canada Inland Waters Directorate Environment Canada, Calgary
S. M. Hirst 1978-1981	Ecologist B.C. Hydro and Power Authority Vancouver, British Columbia
J. Jasper 1978-1981	Hydrologist, Water Resources Div. Northern Affairs Program Department of Indian Affairs and Northern Development Yellowknife, N.W.T.
G. D. Lewis Secretary 1978-1981	Coordinator Mackenzie River Basin Study Inland Waters Directorate Environment Canada, Regina
D. K. MacKay 1978-1981	Chief, Surface Water Division National Hydrologic Institute Inland Waters Directorate Environment Canada, Ottawa
L. Parmley 1978-1981	Senior Hydrologist B.C. Hydro and Power Authority Vancouver, British Columbia

5. Hydrometeorological Network Design Advisory Group

H. Foerstel Chairman, 1978-1981	Head, Planning Division Inland Waters Directorate Environment Canada, Regina
J. Card 1978-1981	Head, Hydrology Branch Alberta Department of the Environment, Edmonton
H. Coulson 1978-1981	Head, Surface Water Section Hydrology Division B.C. Ministry of Environment Victoria, British Columbia
R. A. Halliday 1978-1981	Regional Chief Saskatchewan District Water Survey of Canada Inland Waters Directorate Environment Canada, Regina
J. Jasper 1978-1981	Hydrologist, Water Resource, Div. Northern Affairs Program Department of Indian Affairs and Northern Development Yellowknife, N.W.T.
G. D. Lewis Secretary 1978-1981	Coordinator Mackenzie River Basin Study Inland Waters Directorate Environment Canada, Regina

M. Oreklin 1978-1981	Hydrologist, Water Resources Div. Northern Affairs Program Department of Indian Affairs and Northern Development Whitehorse, Y. T.
N. E. Parsons 1978-1981	Head, Intergovernmental Studies Divison Water Management Service Saskatchewan Department of the Environment, Regina
A. Waroway 1978-1981	Head, Engineering & Planning Section Water Resources Division Northern Renewable Resorces Program Department of Indian Affairs and Northern Development, Ottawa

6. Slave River Delta Advisory Group

S. Metikosh Chairman 1980-81	Senior Aquatic Biologist Water Resources Division Northern Affairs Program Department of Indian Affairs and Northern Development Yellowknife, N.W.T.
R. A. Hale Chairman 1977-1980	Regional Manager Water Resources Division Northern Affairs Program Department of Indian Affairs and Northern Development Yellowknife, N.W.T.
K. Ambrock 1977-1980	Wildlife Biologist Canadian Wildlife Service Environment Canada, Edmonton
S. Bramm 1977-1979	Planning Officer Planning Division Alberta Department of Environment Edmonton
K. Bodden 1977-1980	Research Associate Boreal Institute for Northern Studies University of Alberta, Edmonton
K. Davies 1977-1981	Northern Operations Engineer Water Survey of Canada Inland Waters Directorate Western and Northern Region Environment Canada, Calgary
Dr. D. Gill 1977-1979	Department of Geography University of Alberta, Edmonton
G. D. Lewis Secretary 1977-1981	Coordinator Mackenzie River Basin Study Inland Waters Directorate Environment Canada, Regina
B. Lieff 1977-1981	Superintendent Wood Buffalo National Park Parks Canada Environment Canada Fort Smith, N.W.T.
J. Stein 1977-1981	Head, Impact Assessment Division Environmental Impact Section Canada Department of Fisheries and Oceans, Winnipeg
B. Stephenson	Supervisor, Management Studies Fish and Wildlife Service Government of the Northwest Territories, Yellowknife, N.W.T.

7. Athabasca Sand Dunes Advisory Group

H. T. Epp Chairman 1978-1981	Resource Management Consultant Policy, Planning and Research Branch Saskatchewan Department of the Environment Regina
A. G. Appelby 1978-1981	Director, Land Use Division Department of Northern Saskatchewan Prince Albert, Saskatchewan
G. D. Lewis 1978-1981	Coordinator Mackenzie River Basin Study Inland Waters Directorate Environment Canada, Regina
N. E. Parsons 1978-1981	Head, Intergovernmental Studies Division Water Management Service Saskatchewan Department of the Environment, Regina
W. Runge 1978-1981	Wildlife Ecologist Wildlife Management Program Department of Northern Saskatchewan Prince Albert, Saskatchewan

8. Public Information North of 60° Advisory Group

E. Watt Chairman 1979-1980	Regional Manager Public Affairs Department of Indian Affairs and Northern Development Yellowknife, N.W.T.
R. A. Hale Chairman 1979	Regional Manager Water Resources Division Northern Affairs Program Department of Indian Affairs and Northern Development Yellowknife, N.W.T.
J. Compagnon 1979-1980	Public Affairs Advisor Environmental Management Service Environment Canada, Edmonton
R. Creery 1979	Director, Department of Planning and Program Evaluation Government of the Northwest Territories, Yellowknife, N.W.T.
G. Lewis Secretary 1979-1980	Coordinator Mackenzie River Basin Study Inland Waters Directorate Environment Canada, Regina
A. Sorenson 1979-1980	Director, Department of Information Government of the Northwest Territories, Yellowknife, N.W.T.

9. Photo Credits

Alberta Government Services
Public Affairs Bureau
Edmonton

Environmental Resources Department
B.C. Hydro and Power Authority

B.C. Ministry of Environment
Victoria, British Columbia

Department of Energy, Mines and Resources
Canadian Centre for Remote Sensing
P.A. Satellite Station
Prince Albert, Saskatchewan

Environment Canada
Canadian Wildlife Service
Edmonton

Department of Information
Government of the Northwest Territories
Yellowknife, N.W.T.

Department of Northern Saskatchewan
La Ronge, Saskatchewan

Environment Canada
Northern Forest Research Centre
Edmonton

Environment Canada
National Hydrologic Research Institute
Ottawa

Northern Transportation Co. Ltd.
Edmonton

Outcrop Ltd.
Yellowknife, N.W.T.

Environment Canada
Parks Canada
Wood Buffalo National Park
Fort Smith, N.W.T.

Environment Canada
Parks Canada
Winnipeg, Canada

University of Alberta
Geography Department
(Don Gill Memorial Collection)
Edmonton

Water Resources Division
Department of Indian Affairs and Northern Development
Yellowknife, N.W.T.

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H. Maathuis
B. Paquin
S. Rowe
T. Smith
J. Wilson
R. Wright

Glossary

Appendix E

The glossary was developed from many sources and is presented here to aid readers of this report.

ACIDITY (ACID) - The property of surface water or water in soils and rocks with a pH below 7, and particularly water with a pH below 4.5, caused by the presence of mineral acids.

ACTIVE LAYER - The layer of the soil that usually freezes in the winter and thaws in summer, found immediately above permanently frozen ground.

ACUTELY LETHAL - Describes a substance that produces death in an organism within a short period of time (usually 96 hours or less after exposure).

ADVENTITIOUS ROOT - A root that arises from a plant part other than the primary root or its branches; adventitious roots often develop on stems above the normal rooting zone.

AEOLIAN - Eroded, transported, or deposited by wind action.

AGGRADATION - The deposition or building up of sediments by stream, wave, or wind action. An aggrading river is one that actively elevates its bed by deposition of sediments.

ALBEDO - The fraction of the total sunlight falling on a surface that is reflected back. Snow reflects about 75% and dense forests about 5% of solar radiation. Water reflects between 4% and 40%, depending on its clarity, and absorbs the other 96% to 60%.

ALGAE - Primitive plants, one or many-celled and usually aquatic, capable of photosynthesis, although not all algae produce their food by photosynthesis.

ALLUVIUM (ALLUVIAL) - More or less stratified deposits of sand, silt, gravel, and other coarse debris moved by streams from higher to lower ground. It is the general term for all sediment deposited on land by streams.

ALPINE VEGETATION - Mountain vegetation that grows at altitudes above the timber line, or limit of tree growth.

ANADROMOUS - Fish such as salmon that spend part of their lives in fresh water and part in salt water. They ascend freshwater streams to spawn.

ARCUATE DELTA - An arched or bow-shaped delta, such as the Slave River Delta.

ASSIMILATIVE CAPACITY - The ability of water, for example, to accept pollution without detectable degradation in quality.

BANK - Ascending slope bordering a river or lake. Left and right banks are determined by facing downstream.

BANKFULL - The flow stage of a river in which the stream completely fills its channel from the riverbed to the top of the river banks.

BAR - In rivers, a streamlined deposit of sand and gravel having a steep drop-off side downstream, which is built by currents and may be exposed during low river stages.

BARRENS - An area relatively barren of vegetation. Tundra is called barrens colloquially because it is bare of trees.

BASEFLOW - Streamflow that is composed entirely of groundwater and other inflows, when there is no direct runoff from precipitation or snowmelt.

BASELINE DATA - Data that describe select characteristics of the existing environment, serving as control data against which future changes in the environment can be compared.

BEACH RIDGE - A continuous mound of material heaped up directly behind a beach by waves or wind action.

BEDLOAD - Material dragged along in contact with the bed of a stream.

BEDROCK - Solid rock of the earth's crust exposed at the surface of the earth, or covered with unconsolidated materials such as silts, sands, and gravels.

BENTHIC MACROINVERTEBRATE - Organisms with no backbone that are large enough to see with the naked eye. The prefix benthic means these organisms live on the bottom of water bodies.

BIOLOGICAL FACTORS - The complex of biological factors that work together to bring about a balanced biological system, yet allow for slow change. These factors include the interdependency of organisms that are food producers or storers, and those that are food consumers or users.

BIOME - A large land area with similar vegetation used to define the main ecosystem types of the earth, such as tundra and boreal forest. A biome is a climax community that characterizes a particular natural region.

BIOTA - Living organisms, including plants, animals, and microscopic life, that characterize a given region.

BIRDSFOOT DELTA - A delta formed by the outgrowth of natural levees at the mouths of river distributaries, producing a birdfoot form.

BOG - Peat-covered area with a high water table and a surface carpet of mosses, chiefly sphagnum. The bog is virtually isolated from mineral soil waters; hence the surface bog waters and peat are strongly acid, and the upper peat layers are extremely deficient in mineral nutrients. Bogs may be treed or treeless and may have shrubby plants.

BOREAL FOREST - Northern forests that consist primarily of coniferous trees such as spruce, fir, and pine, but also include deciduous trees such as aspen, birches, poplars, and willows.

BRAIDED STREAM - A stream flowing in several wide and shallow channels which repeatedly divide and re-unite, resembling the strands of a braid.

BUFFERING CAPACITY - The ability of water, for example, to resist a lowering in pH.

CALIBRATION - Adjustment and correction of a measuring device or mathematical model, so that the measurement or model output contains the least possible error when compared against a standard or known result.

CLIMATE - The sum total of the meteorological elements that characterize the average and extreme condition of the atmosphere over a long period of time at any one place or region of the earth's surface. These elements include temperature, moisture, precipitation, wind, pressure, and evaporation.

CLIMAX VEGETATION - The final stage of plant succession for a given natural environment, the stage at which the composition of the plant community remains relatively unchanged as long as the environment remains unchanged.

COMMUNITY - Plants or animals that make up the biological part of an ecosystem.

CONIFER (CONIFEROUS) - Cone-bearing trees with naked seeds and needle-shaped leaves, such as pine, spruce, or fir. Most conifers are evergreen but larch sheds its needles. Conifers are called softwoods because their wood is relatively soft.

CORRASION- Mechanical wear and erosion by moving ice or running water.

CUTBANK - The bank of a meandering stream that is steepened or undercut by water erosion at its base.

DAM - A natural or man-made obstruction in a river valley, such as a lava dam or beaver dam or different types of engineering structures for water storage or hydroelectric power production.

DATA BASE - A collection of information such as contained in automated files, a library, or a set of computer disks.

DEBRIS - Soil and rock materials carried or deposited by gravity, ice, wind, or water. Also, material resulting from the decay and disintegration of rocks.

DECIDUOUS - Trees and shrubs that shed their leaves in the fall.

DELTA - A body of sediment deposited by a stream flowing into a lake or the sea, and usually growing outward. As sediment continues to be deposited, the river is forced to subdivide repeatedly. Deltas are easily recognized by the branching network of large and small distributary channels which results. Small deltas may be formed where meltwaters discharge into a temporary glacial lake, where a river enters a lake, or at the confluence of two rivers - especially where a swift stream heavily laden with sediment joins a much slower and more sluggish stream.

DENSITY OF WATER - The density of water is greatest at 4°C. It becomes less dense as it warms and more important, as it cools to freezing at 0°C. At that temperature, it changes to ice, which floats because its density is less than that of water. Therefore only very shallow lakes and ponds (no more than 2 to 3 m) freeze to the bottom.

DEPOSIT - Any sediment left in a new location by a natural transportation agent, such as water, wind, ice, gravity, or by some activity of man.

DISCHARGE - In the case of a river, the volume of flow per unit time across a given cross-section, usually expressed in cubic metres per second (m^3/s).

DISCLIMAX - An intermediate stage of vegetation succession, maintained in this state by recurrent disturbances that prevent the establishment of a climax community. Repeated browsing or grazing is a common cause of disclimax stands of vegetation.

DISSOLVED OXYGEN - The amount of oxygen in solution in water. The saturation point is higher at colder temperatures, so that cool water can hold more oxygen than warmer water. Organisms that require oxygen (aerobic organisms) cannot survive below certain oxygen levels.

DISTRIBUTARIES - The network of stream channels occurring in a river delta or braided stream, or on an alluvial fan.

DIVERSION - The act of diverting water from a stream or lake to another stream or lake, or to another river basin.

DRAINAGE BASIN - The total area that contributes runoff water to a stream. The amount of water reaching the stream depends on the size of the basin, precipitation, and losses due to deep percolation, evaporation, and absorption by the soil and vegetation, among other factors (also see WATERSHED).

DRAWDOWN - The change in the water level of a natural body of water, well, or reservoir as a result of withdrawing water.

DYNAMIC EQUILIBRIUM - A condition in which several processes act simultaneously to maintain a biologic system in an overall state that does not change with time, or does so very slowly. It is a self-correcting balance between the forces of change and stabilization, superimposed on a continuous flow of matter and energy through the system.

ECOSYSTEM - A natural system of all plants and animals and their environment, and the way they adjust to that environment and each other (derived from the words ecological system).

ECOTONE - Transition area between two adjacent biomes or ecological zones, usually exhibiting competition between plants and animals common to both, as between forest and grassland or between boreal forest and adjoining tundra.

EMERGENT VEGETATION - Aquatic plant species that have their stems or leaves extending above the water surface, such as bulrush or cattail.

ENDEMIC - Peculiar to a certain region.

ENVIRONMENT - The sum of all external forces, conditions, and influences that affect the existence and development of plants and animals. Air, light, moisture, temperature, wind, soil, and other organisms are called environmental factors (also see ECOSYSTEM).

EQUILIBRIUM - A condition in which no change occurs in the state of a system as long as its surroundings are unaltered. There may be static or dynamic equilibrium.

EROSION - The wearing away and removal of soils, rocks, and landforms by the physical and chemical action of moving water, ice, air, and gravity. Simply, the detachment and movement of soil or rock by water, wind, ice, or gravity.

ESTUARY (ESTUARINE) - A coastal inlet that is the lower course or mouth of a river where salt and fresh water mix and tidal effects are evident.

EVAPOTRANSPIRATION - The combined loss of water from a given area by evaporation from the soil surface and by transpiration from plants growing on the land.

FALSE-COLOUR COMPOSITES - Images obtained by scanning the earth's surface in four wavelengths from a satellite (such as LANDSAT), and combining selected wavelengths in various ways as false-colour composites. For example, images with an overall red colour show vegetated surfaces and images with predominantly blue colour are useful for delineating land/water boundaries.

FAUNA - The aggregation of animal species characteristic of a certain locality, region, or environment. The animals found fossilized in certain geologic formations or occurring in specified time intervals of the past may be referred to as fossil fauna.

FENS - Peatlands characterized by surface layers of poorly to moderately decomposed peat. Sedges dominate in fens although grasses, reeds, shrubs, and a sparse layer of trees may be present. Usually there is slow internal drainage of waters that are less acidic than waters of bogs in the same area.

FLASH FLOOD - A flood of short duration with a relatively high peak rate of flow, usually resulting from a high intensity rainfall over a small area.

FLOATING ICE - Any form of ice found floating in water, or temporarily stranded or grounded.

FLOOD - Any relatively high level or flow of water that overtops natural or artificial banks in a lake or any reach of a river.

FLOODPLAIN - The flat land bordering a stream, built up of sediments from overflow of the stream and subject to inundation when the stream is at flood stage.

FLORA - The assemblage of plants of a given biophysical zone, region, or local area.

FLUSHING TIME - The interval of time needed for an amount of water equal to the volume of a lake to pass through its outlet. It is computed by dividing the lake volume by the flow rate (usually mean annual flow) at the outlet.

FLUVIAL PROCESSES - Processes associated with stream action such as erosion and deposition and development of landforms (for example floodplains), channels, and habitat.

FOOD CHAIN - The transfer of food energy from plants (converted by them from solar energy through photosynthesis) to other plants and to animals, through repeated stages of eating and being eaten. There may be as few as two links in a food chain or as many as five.

FRAZIL ICE - A mush of ice spikelets and water resembling slush, formed by freezing in turbulent flowing water. Frazil ice formed in turbulent waters at rapids and waterfalls during prolonged cold spells is granular or spiky.

GAUGE - An instrument for measuring and recording the stage of a river or amount of rainfall, termed river gauge or rain gauge, respectively. It may have an automatic recording device.

GEOMORPHIC PROCESSES - All those physical and chemical processes that change the earth's landforms and landscapes.

GEOMORPHOLOGY - The study and scientific interpretation of topographic features (landforms).

GROUND COVER - The mat of vegetation on or over the soil surface. It may consist of herbaceous plants, mosses, etc., and is usually measured in terms of the percentage of the ground it covers.

GROUNDWATER - Subsurface water occurring below the water table, that is, in the saturated zone in which all soil pores are filled with water. The water above the water table is referred to as soil moisture.

HABITAT - An area which provides physical and biological conditions suitable for the survival of animal or plant populations.

HEADWATERS - The upper reaches of a drainage system, or the waters upstream of an engineering structure.

HERBICIDE - A substance used to destroy plants or inhibit their growth.

HORSETAIL (Equisetum Fluviatile) - Aquatic emergent plant which is a major primary producer in wetland ecosystems.

HOTSPRING - A thermal spring with a water temperature above $37^{0}C$.

HYDROGRAPH - A graph showing the flow (discharge), stage (level), velocity, or other characteristics of flowing water at a given location over time. This provides a picture of river flow variations from day to day and year to year.

HYDROLOGIC CYCLE - Also known as the water cycle. This is the never-ending circulation of water and water vapour over the entire earth, from the atmosphere to the surface of the earth and back to the atmosphere, by precipitation, runoff, percolation, storage, evaporation, and transpiration.

HYDROLOGY - A scientific and engineering discipline dealing with the occurrence of water on and under the earth's surface, its physical and chemical properties, as well as its distribution and movement.

HYDROMETEOROLOGY - The part of meteorology that deals with the rates and volumes of precipitation and the weather conditions that affect its distribution and movement on the ground (snowmelt, river freezeup and breakup, storms, floods).

HYDROMETRIC DATA - Measurements of river flow and water level (also see WATER QUANTITY).

HYDROMETRIC GAUGE - Also known as a current meter. A metering device used to measure the velocity of a river's current (also see STREAMFLOW).

ICE JAM - An accumulation of broken river ice or sea ice caught in a narrow channel.

ICE LENS - A discontinuous layer of ground ice tapering at its extremities. Ice lenses in soil occur roughly parallel to each other, generally coincident with the direction of heat loss, and commonly in repeated layers.

ISOSTATIC REBOUND - The springing back of the earth's surface to its former level, following the recession of a glacier and the consequent removal of weight from the earth's surface.

LANDFORM - A land feature described by its size, shape, and slope. Landforms include mountains, plains, valleys, deltas, dunes, and pingos.

LANDSAT IMAGE - Representation of the natural and cultural features of the earth's surface which may look like, but is not, a photograph (also see FALSE - COLOUR COMPOSITES).

LEVEE - Low ridge of fine alluvium deposited along the side of a river when a river overspreads its banks. It is commonly the highest part of a floodplain and slopes away from the river.

LIMNOLOGY - The scientific study of standing bodies of fresh water. In its broadest sense limnology deals with all geological, physical, chemical, and biological conditions of ponds and lakes and the life in them.

LOCAL INFLOW - The summation of all ungauged inflowing streams along a river reach.

MATHEMATICAL MODEL - A series of calculations and equations that simulate the action of a prototype or real situation numerically. In this study, a mathematical model was developed to simulate the hydrologic conditions in the river and to compute the consequences of proposed water resource projects on water flows downstream.

MEAN ANNUAL DISCHARGE - Essentially the daily flow of water averaged over the length of time that records are available (the period of record). It is calculated by taking the arithmetic mean of the "annual mean discharge" (that is, the annual mean of daily discharges for an entire single year) for all years over the period of record.

METEOROLOGY - The scientific study of the atmosphere and its phenomena, including its effects on the earth's surface, the oceans, and life in general.

METRIC UNITS - The International System of Units (SI), which is a rationalized system of metric units, is used throughout the report. Two units may not be familiar to the general reader:

m^3/s (cubic metres per second, equivalent to 0.028317 cubic feet per second in the English system of units) used to measure the flow rate of a river

dam^3 (cubic decametres, equivalent to 1.2335 acre-feet) a much larger unit of calculated volume used for annual flow volumes or large storage quantities.

MICROCLIMATE - The climate near the ground, as influenced by variations in kind of soil, vegetation cover, shading, or wind protection.

MIGRATORY BIRDS - Birds capable of celestial navigation that move periodically or seasonally from one region or climate to another.

MUSKEG - A type of bog, often with a mat of vegetation and scattered black spruce or tamarack (larch) trees.

NEGATIVE ENERGY BALANCE - A net loss of energy from the earth to the atmosphere.

NUTRIENT - Something that gives nourishment and promotes development (i.e. food).

OLIGOTROPHIC LAKES - Deep and geologically young lakes, deficient in organic materials, whose waters contain a high degree of dissolved oxygen accompanied by a low biological oxygen demand (BOD).

OXBOW LAKE - A crescent-shaped lake formed in an abandoned river bend (meander) that has become separated from the main stream by a change in the course of the river, usually by the stream cutting through the narrow neck of the bend.

PARABOLIC DUNE - A sand dune in the form of a parabola or U-shape, with the concave (open) side and the two "wings" facing the wind. It occurs where vegetation at least partially covers the sand.

PARAMETER - A variable in a model equation or other mathematical relationship which, for each of its particular values, defines other variables in that relationship. By changing the parameter values, for example, the action of a mathematical model can be changed.

PERCHED BASIN - A basin whose surface water level is above that of the surrounding general water table and is separated from underlying groundwater by an impermeable bed.

PERMAFROST - Perennially frozen ground occurring wherever the temperature remains below 0°C for several succeeding years. It may be continuous, discontinuous (scattered), or localized.

pH - A measure of acidity or alkalinity of soil or water. Distilled water is neutral, with a pH value of seven. Values above seven indicate an alkaline state, while those below seven indicate an acidic state.

PHOTOSYNTHESIS - Biochemical process by which green plants convert energy from sunlight to plant food, by combining carbon dioxide and water in the presence of chlorophyll.

PHYSIOGRAPHIC REGION - Region of similar large-scale topography, geologic structure and history.

PINGOS - Small dome-shaped hills composed of ice, 10-100 m in diameter, and raised by frost action as much as 30 m above the surrounding terrain.

POLYGONS - Patterns of cracks in permafrost areas, generally produced by alternate freezing and thawing of the surface soil.

PRECAMBRIAN SHIELD - Also known as the Canadian Shield or simply Shield. The huge tract of land in subarctic Canada that extends from the Atlantic to the Arctic Ocean and is composed of the oldest rocks of the earth's crust. Its low relief surface shows the effect of intense continental glacier erosion.

PRIMARY PRODUCTIVITY - The rate at which radiant energy is stored by the photosynthetic activity of green plants in the form of organic substances that can be used as food materials.

PROGRADATION - The outward advance of a shoreline resulting from the nearshore deposition of sediments by a river.

PROJECT CONDITION - This term is used in mathematical modelling in hydrology to describe an assumed river condition being tested by the model (usually to represent the effects of a project), as opposed to the observed condition.

RAPTOR - A bird adapted for snatching or seizing living prey, and commonly referred to as a bird of prey.

REACH - A particular section or length of river considered as a unit for study, design, mathematical modelling, or descrip- tive purposes.

RELIEF MAP - A map that shows the difference in altitude between higher and lower areas of land.

RESERVOIR - Artificial lake created behind a dam for storing water or producing hydroelectric power.

RIPARIAN - Living or located on a river bank.

RIVERBED - The lower and normally submerged part of a river channel, excluding the banks of a stream.

RIVER CHANNEL - The space above the riverbed and between the banks of a stream.

RIVER PROFILE - The slope or gradient of a river from its source to its mouth. Initially it is often irregular, with rapids and waterfalls in its upper reaches, but over geologic time the profile is smoothed out by erosion.

RIVER REGIME - The flow characteristics of a river with respect to velocity, volume, form of and alterations in the channel, amount of sediment produced, and the river's capacity to transport it.

RIVER STAGE - The level of the water surface.

ROUTING - The technique of calculating the hydrography of a downstream location from the hydrograph of an upstream location in that river system, taking local inflows and the effects of intervening channel, valley, and lake storage into account. Routing changes the shape of the hydrograph, usually by flattening out the peaks and valleys.

RUNOFF - The portion of the total precipitation on an area that flows away in surface streams.

SAND DUNE - A low ridge or mound of loose sand formed by wind or water action. Wind-deposited dunes are commonly formed under desert and semi-desert climatic conditions by moving wind or water, and exhibit steeper downstream or downwind slopes. They are frequently found on inactive sandy floodplains, outwash plains, glacial lake deltas and sandy lakebeds, and along seashores.

SECONDARY PRODUCTIVITY - The rate of energy storage by consumer organisms (animals) in an ecosystem.

SEDGES - Grasslike plants that typically have solid triangular-shaped stems, as opposed to grasses whose stems are cylindrical or flattened in shape. Sedges inhabit marshy places, the banks of streams, and the shores of ponds and lakes.

SEDIMENT - All soil and rock particles resulting from the weathering of rock and removed by water, air, ice, or gravity. When the water velocity decreases in a river, this suspended material settles out but may be successively picked up again and re-deposited.

SENSITIVE AREAS - For the purposes of this study, an area of potential value (social, cultural, scenic, or ecological) that may be sensitive to changes in the water regime.

SERE - The whole sequence of vegetation communities that replace one another in a given area. The transitory communities that precede the climax vegetation are called seral stages.

SHOAL - A shallow area in flowing or standing water, produced by sediment deposition. Commonly refers to near-surface ocean, lake, or stream bottoms, especially when the shoals endanger navigation.

SILTING - The deposition of waterborne sediments in stream channels, lakes, reservoirs, or on floodplains, usually resulting from a decrease in the velocity of the water.

SIMULATION - The technique of producing, usually through mathematical modelling, a graph or other description that represents a real or observable situation (for example, the effects of a project on river flow downstream).

SLUMPING - A type of landslide characterized by the downward slipping of a mass of rock or unconsolidated material, sometimes slowly and intermittently and sometimes in one rapid movement.

SNOWCOURSE - A series of selected points in a line up to one kilometre long, where measurements of snow depth, density, and water content are made.

SNOWMELT - Water resulting from melting snow.

SPRING BREAKUP - The destruction of the winter ice cover by the combined forces of solar radiation and high runoff from snowmelt. The sun initially weakens the ice cover. The water flowing under the ice then fractures and uplifts it, as the volume of flow increases, and moves the broken ice downstream.

SPRING FLOOD - High streamflow that overtops the river banks when snowmelt increases the runoff sharply each spring.

SPRING FRESHET - The annual spring rise in the water level of streams in cold climates as a result of influx of water from melting snow.

SOLIFLUCTION - The slow downhill flow of surface deposits saturated with water released by thawing. Mostly limited in usage to such movements in permafrost or periglacial regions.

SPECIES - A group of plants or animals that normally interbreed, producing fertile offspring, and that resemble each other in structure, habits, and functions.

STREAM - A body of running water moving under the influence of gravity to lower levels in a narrow, clearly defined natural channel. Streams are referred to as brooks, creeks, streams, and rivers.

STREAMFLOW - The flow of surface water between well-defined stream or river banks. The volume of flow is calculated by multiplying the measured velocity of water by the cross-sectional area of the river at that point, and is expressed in cubic metres per second (m^3/s).

SUCCESSION - The orderly progression of one type of plant community gradually replacing another. Generally, it is the dominant species in each stage that alters the environment in a way that ushers in the next stage. Succession is reasonably directional, and therefore the duration of each stage and the plants and animals that make up each succession stage can be predicted (also see CLIMAX VEGETATION).

SURFACE WATER - Also called fresh water. Water from rain, snowmelt, or springs, standing on or flowing over the ground.

SUSPENDED SOLIDS (SEDIMENT) - The solid material suspended in a stream. It may be carried a great distance or for a considerable period of time by current and turbulence.

TAILINGS - The waste material resulting from processed ore.

TERRACE - A nearly level, usually narrow plain bordering a river or lake. Rivers are often bordered by a number of terraces where another valley floor has eroded below the bottom of a former valley floor. Alluvial terraces are particularly prominent along valleys that carried glacial outwash.

THERMOKARST LAKE - All relief forms, such as lakes, ponds, or other depressions, produced by settling or caving of the ground surface as a result of ground ice melting in the upper layer of permafrost.

TOPOGRAPHY - The general configuration of a surface, including its relief. It may be a land or water-bottom surface.

TOTAL DISSOLVED SOLIDS - The quantity of minerals in solution in water, usually stated in nearly equivalent terms of parts per million (ppm) or milligrams per litre (mg/L).

TOXIC SUBSTANCE - Any inorganic or organic substance having a poisonous effect on any form of life.

TRANSPARENCY - The depth of water to which sufficient light can penetrate for plants to carry on photosynthesis. The depth decreases as increasing amounts of suspended materials make the water more turbid.

TRANSPIRATION - The process by which water exhales or escapes from the pores of living plant tissues and enters the atmosphere. Transpiration is the water discharge of vegetation.

TUNDRA - Undulating and treeless arctic plain with perennially frozen, patterned ground. The impermeable near-surface permafrost table creates marshy conditions on the surface in summer. The summers are short, but the days long. Vegetation consists mainly of mosses, lichens, sedges, herbs, and dwarf species of alder, birch, and willow.

UNDERSTORY - The lower of two or more vegetation layers on a site.

UNGULATE ANIMALS - A mammal with hoofs, for example, moose, deer, horses.

WATDOC - A bibliographic information service operated by Environment Canada, providing convenient online access to several computer-stored environmental data bases through QL Systems Ltd. of Kingston, Ontario. About 1700 document references to the Mackenzie Basin can be accessed in the WATDOC data base called Canadian Environment.

WATER BUDGET - The hydrologic balance of a river basin consisting of a systematic summary of the inflow, storage, losses, and outflow of water for the entire watershed.

WATER QUANTITY - Amount of water available in a river basin, based on measurements of river flow and water levels in rivers and lakes.

WATERSHED - The area that supplies water to a stream by direct runoff and by groundwater runoff.

WATER TABLE - The level below which the ground is completely saturated with water (also see GROUNDWATER).

WEIR - A barricade across a stream over which water flows. It may be constructed to raise the water level or to measure streamflow.

WIND SETUP - The vertical rise of the water level in a lake or reservoir above its normal still water level, caused by wind pushing the water up the shore toward which it is blowing.

Figure 2.12

Mackenzie River System

Figure 2.20

Drainage Subbasins

Figure 6.1

Selected Development Possibilities

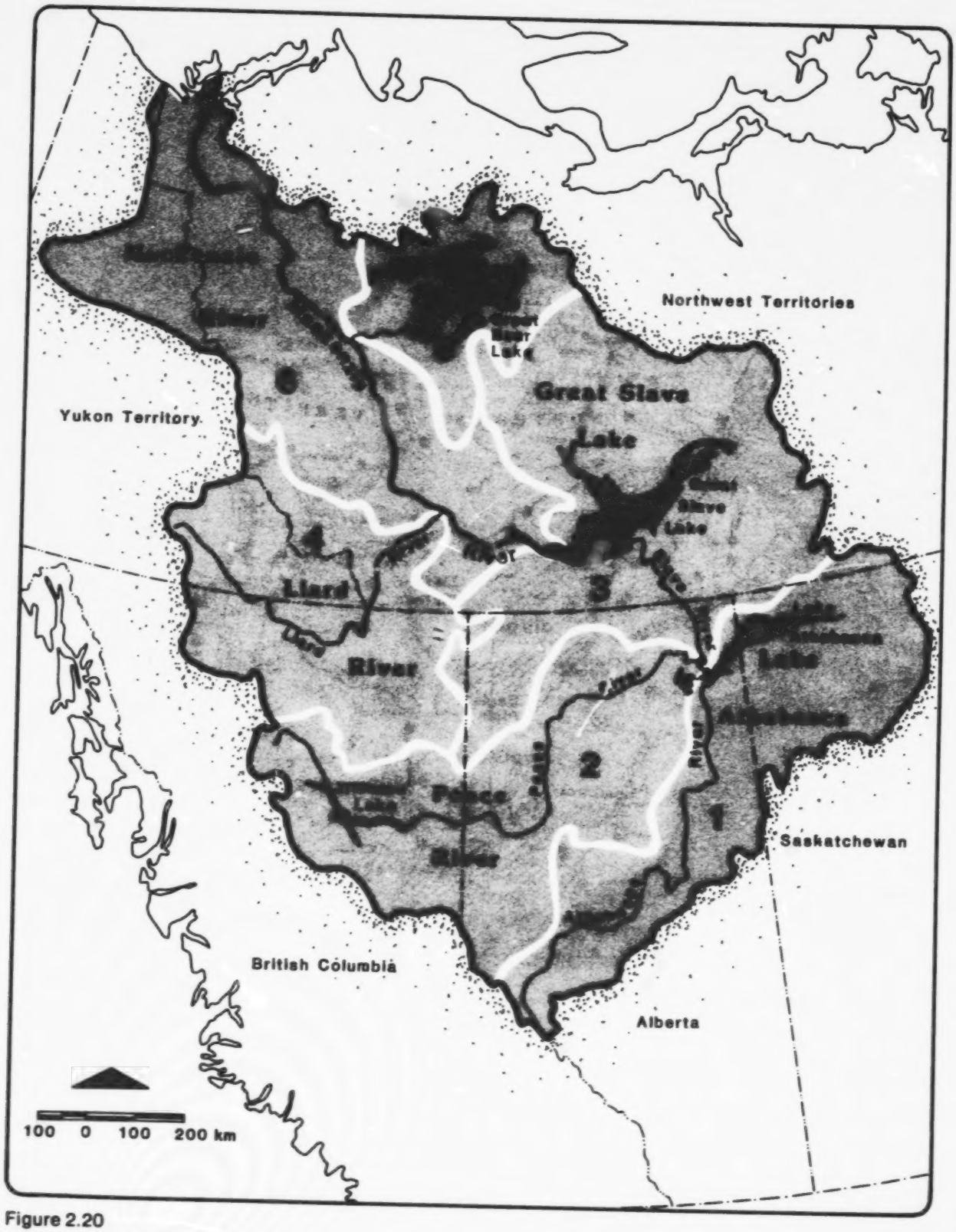

Figure 2.20

Drainage Subbasins

Figure 6.1

Selected Development Possibilities

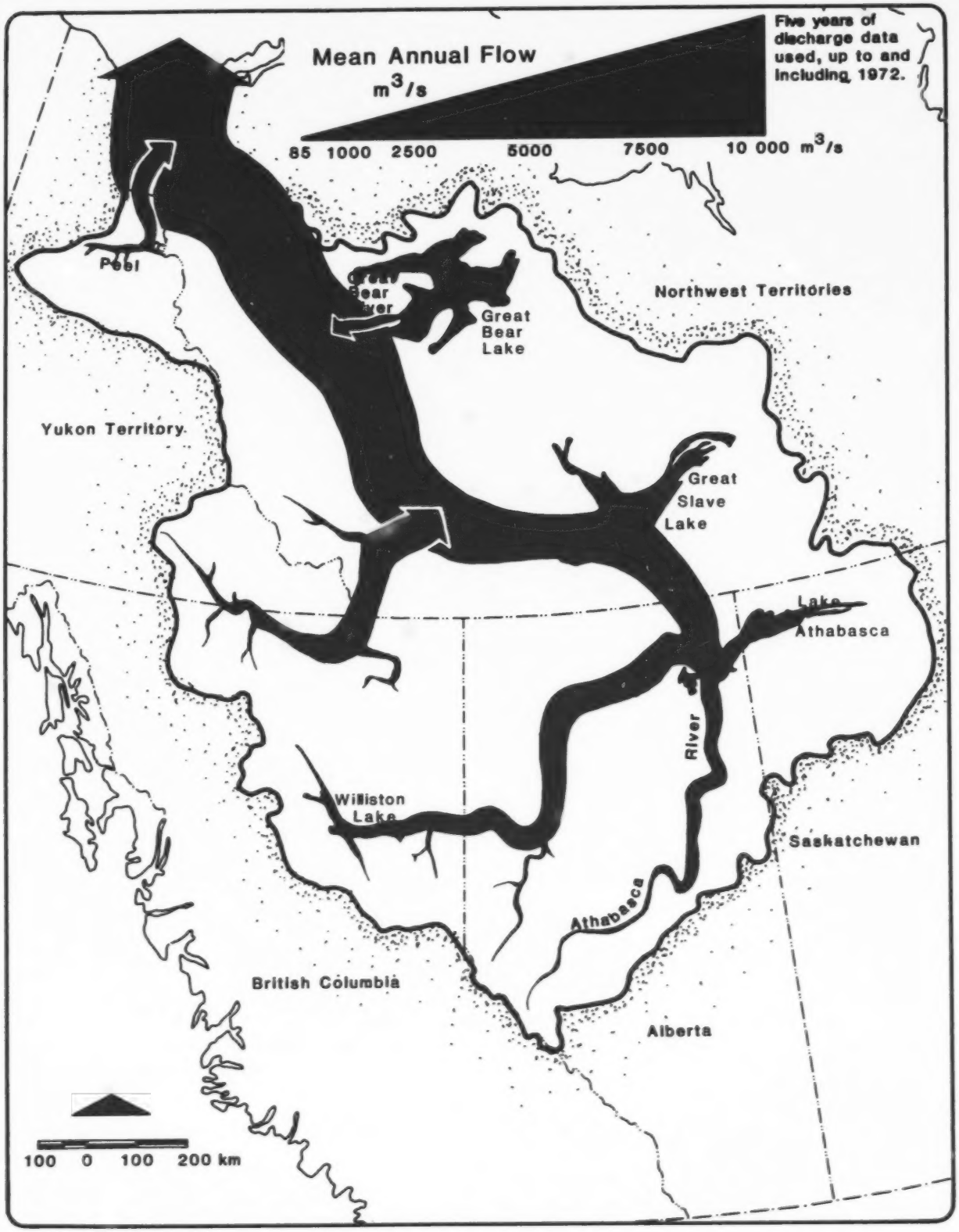

Figure 2.12

Mackenzie River System

POOR

QUALITY

ORIGINAL